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Fecundity Changes in Exploited Populations of Lake Whitefish (*Coregonus clupeaformis*) and Lake Trout (*Salvelinus namaycush*)

M. C. HEALEY

Department of Fisheries and the Environment, Fisheries and Marine Service, Research and Resource Services, Pacific Biological Station, Nanaimo, B.C. V9R 5K6

HEALEY, M. C. 1978. Fecundity changes in exploited populations of lake whitefish (*Coregonus clupeaformis*) and lake trout (*Salvelinus namaycush*). J. Fish. Res. Board Can. 35: 945–950.

This report considers the possibility that exploited populations of lake whitefish (*Coregonus clupeaformis*) and lake trout (*Salvelinus namaycush*) may show increased individual fecundity. Average fecundity of both species in three exploited lakes varied significantly between 1972 and 1976, while fecundity in an adjacent unexploited lake did not vary. Changes in the fecundity of whitefish and trout in the exploited lakes were not clearly related to the pattern and intensity of exploitation, but fecundity of both species increased in all exploited lakes after exploitation, with trout showing the greater response.

Key words: fecundity, lake whitefish, lake trout, exploitation, northern Canada

HEALEY, M. C. 1978. Fecundity changes in exploited populations of lake whitefish (*Coregonus clupeaformis*) and lake trout (*Salvelinus namaycush*). J. Fish. Res. Board Can. 35: 945–950.

On examine dans cet article la possibilité que des populations exploitées de grands corégones (*Coregonus clupeaformis*) et de touladis (*Salvelinus namaycush*) accusent une fécondité individuelle accrue. Le fécondité moyenne des deux espèces dans trois lacs exploités varia de façon significative entre 1972 et 1976, alors qu'elle demeura la même dans un lac inexploité du voisinage. Ces changements dans la fécondité du grand corégone et du touladi dans des lacs exploités ne sont pas clairement associés aux modalités et à l'intensité de l'exploitation, mais la fécondité des deux espèces augmenta dans tous les lacs exploités une fois l'exploitation commencée, le touladi réagissant plus que le grand corégone.

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ANNUAL variations in individual fecundity are well documented for marine fish populations (Bagenal 1957, 1967), but not for freshwater fishes, although Nikolsky (1963) reports variation in fecundity within populations of freshwater fishes. Healey and Nicol (1975) and Healey (1975, 1978a) reviewed the available information on fecundity of lake whitefish (*Coregonus clupeaformis*) and lake trout (*Salvelinus namaycush*), and pointed out that there was considerable variation between populations. Whether exploitation of stocks would result in an increase in individual fecundity could not be determined from the available information. Nor could it be determined whether fecundity fluctuated from year to year in these species, although Bell et al. (1977) found no significant annual variation in the fecundity of whitefish from Lesser Slave Lake.

Fluctuation in fecundity and its importance to the dynamics of animal populations has been widely discussed in the ecological literature (Southwood 1968; Wynne-Edwards 1962; Nikolsky 1963; Meats 1971). While it is generally agreed that fecundity of some animals may be reduced at high population densities, or that exploitation may stimulate an increase in fecundity, there is no general agreement on the mechanism leading to variations in fecundity. For commercially exploited fishes, however, an increase in fecundity with exploitation is one mechanism by which surplus production may be affected. An understanding of the relationship between fecundity and exploitation is, therefore, important to the general theory of population regulation and to the management of fisheries.

From 1971 to 1976 I conducted a controlled exploitation experiment on Alexie, Baptiste, Chitty, and Drygeese lakes near Yellowknife in the Northwest Territories. My principal objective was to describe the response of the lake whitefish populations to exploitation (Healey 1973). I also collected information on the lake trout populations which were exploited along with the whitefish. Whitefish and trout might respond to exploitation by an increase in individual fecundity, either in connection with increased growth or simply in response to reduced population density. The purpose of this report is to present information on the fecundity of whitefish and trout from the four lakes and to test the hypotheses (1) that fecundity of whitefish and trout remained constant from year to year in unexploited Baptiste Lake, and (2) that fecundity of whitefish and trout increased after exploitation in Alexie, Chitty, and Drygeese lakes, and that the increase was proportional to the rate of exploitation.

Materials and Methods

The design of the experiment, information on general limnology, and some preliminary data on fecundity are presented elsewhere (Healey 1973, 1977, 1978b; Healey and Woodall 1973; Healey and Kling 1975; Healey and Nicol 1975). The lakes ranged 305–547 ha in area and 20–34.5 m in maximum depth. They were chemically typical of oligotrophic lakes near the margin of the Precambrian shield, and very similar in their biological communities. The lakes were all within about 1 km of each other and were selected for their geographic proximity and limnological similarity so that any variability not related to experimental manipulation would be minimal. Large fish species included northern pike (*Esox lucius*), cisco (*C. artedii*), and burbot (*Lota lota*) in addition to whitefish and trout.

I sampled the fish populations in 1971 and 1972, prior to any exploitation. Fish catches in those years suggested total populations of ~10 000 whitefish and 5000 trout in each lake prior to exploitation. These estimates were confirmed by the decline in catch with fishing in Drygeese and Alexie which indicated total populations of 15 000 whitefish and 7000 trout in Drygeese, and 12 000 whitefish and 7000 trout in Alexie (M. C. Healey, unpublished data). The accuracy of these estimates is, however, not within ±50%. In 1973 and 1974 I removed, each year, ~10% of the standing stock of whitefish and trout from Chitty Lake, ~20% from Alexie, and ~30% from Drygeese (based upon the above population estimates), retaining Baptiste as an unexploited control. During 1975 and 1976 I monitored the fish populations in all four lakes. I performed all sampling and exploitation by gill net, using mesh sizes ranging from 38 to 140 mm stretched measure.

I recorded fork length, round weight, sex, and maturity of all whitefish and trout captured. From 1972 to 1976 I preserved both ovaries from maturing whitefish and trout in 10% formalin for later estimation of fecundity, except that in 1975 I collected only whitefish ovaries from Alexie and Drygeese. I made total counts of the eggs in both ovaries of trout, but estimated the fecundity of whitefish from the ratio of the weight of a subsample of 2000 dry eggs to the total dry weight of eggs in the ovaries (Healey and Nicol 1975). Only ovaries in which maturing eggs were clearly separable from immature eggs were suitable for fecundity estimates, and this severely limited sample size. I aged the whitefish by scales but did not age the trout, as scales collected for this purpose were virtually unreadable.

I compared fecundity between years in each lake by analysis of covariance. For the whitefish, I used length and age (all variables transformed to natural logarithms) or weight (variables untransformed) of the fish as covariates. For the trout, length (transformed) or weight (untransformed) were the covariates. I compared fecundity between lakes by standard errors of adjusted treatment means and by plots of fecundity against length over the normal length range of mature fish. "Adjusted treatment means" here refers to the adjustment of average fecundity to average size and age of fish in the samples by means of the covariance analysis (Steel and Torrie 1960). For the purpose of comparison in the tables, fecundities are presented for a standard 45-cm whitefish or 55-cm trout.

Results

During 1973 and 1974 I removed a total of 6439 whitefish (5287 kg) and 2199 trout (2577 kg) from Drygeese, 3311 whitefish (3190 kg) and 1630 trout (1938 kg) from Alexie, and 1660 whitefish (1247 kg) and 395 trout (632 kg) from Chitty. Declines in fishable stock resulting from these removals were indicated by declines in catch per unit effort of each species in each lake (Table 1). Exploitation of whitefish resulted in a marked drop in the size and age of the population

TABLE 1. Catch per unit effort, mean length, and mean age of whitefish and trout at the beginning and end of exploitation in Chitty, Alexie, and Drygeese lakes.

Lake	Species	Time	CPUE	$\bar{x}$ Length (cm)	$\bar{x}$ Age (yr)
Chitty	Whitefish	Start	14.41	40.13	7.92
		End	12.25	41.07	7.35
	Trout	Start	7.43	53.04	—
		End	3.71	54.17	—
Alexie	Whitefish	Start	18.84	41.8	8.94
		End	6.83	42.8	7.54
	Trout	Start	11.00	49.01	—
		End	3.50	36.52	—
Drygeese	Whitefish	Start	25.67	41.95	9.36
		End	1.71	28.50	5.06
	Trout	Start	14.80	48.15	—
		End	1.69	38.27	—

TABLE 2. Ovary pairs of lake whitefish sampled (n), mean age (yr), mean length (cm), mean weight (kg), mean fecundity (1000's), and fecundity adjusted to 45-cm fork length.

Lake		Year 1972	1973	1974	1975	1976	All
Baptiste	n	13	9	11	0	21	54
	$\bar{x}$ age	8.5	7.7	8.4	—	9.2	8.6
	$\bar{x}$ length	42.7	42.5	42.6	—	43.5	43.0
	$\bar{x}$ weight	1.12	1.08	0.998	—	1.02	1.05
	$\bar{x}$ fecundity	26.3	23.4	24.7	—	26.0	25.4
	Adj. fecundity	30.6	27.6	28.9	—	28.7	29.0
Chitty	n	14	14	28	0	15	71
	$\bar{x}$ age	7.8	8.4	7.9	—	8.8	8.2
	$\bar{x}$ length	40.9	42.1	42.5	—	43.3	42.3
	$\bar{x}$ weight	0.887	1.07	1.05	—	1.10	1.03
	$\bar{x}$ fecundity	17.0	22.6	25.4	—	28.4	23.5
	Adj. fecundity	21.2	26.3	29.0	—	31.1	27.1
Alexie	n	16	14	21	11	15	77
	$\bar{x}$ age	8.3	9.0	9.0	9.9	9.8	9.1
	$\bar{x}$ length	43.9	43.7	44.2	44.5	44.3	44.1
	$\bar{x}$ weight	1.19	1.12	1.22	1.28	1.19	1.20
	$\bar{x}$ fecundity	24.0	27.8	31.1	26.5	30.9	28.2
	Adj. fecundity	26.4	31.2	33.4	27.7	32.9	30.5
Drygeese	n	12	19	4	3	5	43
	$\bar{x}$ age	9.5	11.0	8.3	8.1	7.3	9.6
	$\bar{x}$ length	47.8	47.7	44.8	41.8	42.3	46.4
	$\bar{x}$ weight	1.48	1.34	1.38	1.12	1.01	1.33
	$\bar{x}$ fecundity	35.6	26.9	32.0	15.8	25.2	28.3
	Adj. fecundity	29.5	22.5	32.4	19.8	30.6	25.8

in Drygeese, a drop in age in Alexie, but little change in Chitty (Table 1). Exploitation of trout resulted in a drop in size in Drygeese and Alexie but no drop in Chitty (Table 1). During 1971, 1972, 1975, and 1976 in Chitty, Alexie, and Drygeese, and throughout the study in Baptiste I removed ~100 whitefish and 50 trout from each lake each year. Only a few of these yielded ovaries suitable for fecundity estimation, however.

Whitefish from which I took ovaries ranged 36–53 cm fork length (0.6–2.2 kg) and 6–14 yr old, while trout ranged 46–81 cm (1.0–8.4 kg). The samples from each lake covered the size range of mature fish of both species. Drygeese samples had the oldest and largest whitefish, and Chitty samples the smallest and youngest

TABLE 3. Ovary pairs of lake trout sampled (n), mean length (cm), mean weight (kg), mean fecundity (1000's), and fecundity adjusted to 55-cm fork length.

Lake		Year 1972	1973	1974	1976	All
Baptiste	n	5	1	4	18	28
	$\bar{x}$ length	53.7	53.0	52.0	51.8	52.2
	$\bar{x}$ weight	1.87	1.62	1.58	1.76	1.75
	$\bar{x}$ fecundity	2.22	1.39	2.22	2.03	2.06
	Adj. fecundity	2.40	1.55	2.64	2.44	2.42
Chitty	n	8	34	7	4	53
	$\bar{x}$ length	54.1	53.9	55.4	56.5	54.3
	$\bar{x}$ weight	1.74	1.77	2.72	2.34	1.93
	$\bar{x}$ fecundity	1.77	2.27	3.16	3.77	2.37
	Adj. fecundity	1.83	2.37	3.12	3.55	2.44
Alexie	n	3	21	7	7	38
	$\bar{x}$ length	50.0	51.4	51.4	51.3	51.3
	$\bar{x}$ weight	1.42	1.56	1.58	1.55	1.55
	$\bar{x}$ fecundity	1.99	1.75	2.10	2.56	1.96
	Adj. fecundity	2.68	2.15	2.58	3.17	2.44
Drygeese	n	10	40	13	1	64
	$\bar{x}$ length	54.5	50.6	52.9	47.0	51.6
	$\bar{x}$ weight	2.16	1.58	2.01	1.38	1.75
	$\bar{x}$ fecundity	2.06	1.76	2.93	2.58	2.02
	Adj. fecundity	2.12	2.25	3.28	4.09	2.43

(Table 2); Chitty samples had the largest trout and Alexie samples the smallest (Table 3). Average size and age varied somewhat between years in the samples from each lake, but the only systematic changes between 1972 and 1976 were an increase in the length of whitefish from Chitty and a decrease in the length of trout from Baptiste (Tables 2, 3).

In Baptiste, variation in average fecundity of whitefish and trout between years was not significant, whether length and age of whitefish, length of trout, or weight of either were used as covariates (Tables 2, 3, 4). However, sample size of trout was very small except in 1976. There were no trends in fecundity in unexploited Baptiste that were related to the pattern of exploitation in the other lakes.

All the exploited lakes exhibited significant year-to-year variation in fecundity of whitefish, or trout, or both (Tables 2, 3, 4). In Chitty, the most lightly exploited lake, adjusted fecundity of both species increased significantly from 1972 through 1976 (Table 4). In Alexie, whitefish-adjusted fecundity increased from 1972 to 1974, decreased in 1975, and increased again in 1976. These variations just failed to be significant at the 5% level (Table 4). Trout fecundity in Alexie declined between 1972 and 1973, and increased again in 1974 and 1976. These changes were significant (Table 4). In Drygeese, adjusted fecundity of whitefish declined from 1972 to 1973, was highest in 1974, fell lowest of all in 1975, and increased again in 1976. These changes were highly significant in spite of the small sample size (Table 4). Trout fecundity in Dry-

TABLE 4. Analysis of covariance results in the comparison of fecundity of whitefish and trout between years. F = variance ratio for comparison of adjusted treatment means in the covariance analysis.

Lake	Covariates in the analysis	F	Correlation coefficients: Partial — Age	Simple — Length	Simple — Weight
		Whitefish			
Baptiste	Length and age	0.158	0.134	0.659[b]	—
	Weight	1.178	—	—	0.841[b]
Chitty	Length and age	4.712[b]	0.148	0.500[b]	—
	Weight	4.154[b]	—	—	0.588[b]
Alexie	Length and age	2.921	0.196	0.671[b]	—
	Weight	2.300	—	—	0.711[b]
Drygeese	Length and age	4.587[b]	−0.165	0.629[b]	—
	Weight	2.652[a]	—	—	0.718[b]
		Trout			
Baptiste	Length	1.700	—	0.503[b]	—
	Weight	1.589	—	—	0.575[b]
Chitty	Length	5.326[b]	—	0.485[b]	—
	Weight	4.475[b]	—	—	0.841[b]
Alexie	Length	4.611[b]	—	0.584[b]	—
	Weight	4.912[b]	—	—	0.742[b]
Drygeese	Length	12.160[b]	—	0.677[b]	—
	Weight	9.896[b]	—	—	0.846[b]

[a] $P < 0.05$.
[b] $P < 0.01$.

geese increase significantly from 1972 to 1976 (Table 4).

Fecundity was significantly correlated with length and weight in all samples, but consistent with the finding of Bell et al. (1977), age did not contribute significantly to the multiple correlation of fecundity with length and age in whitefish (Table 4).

Correlation coefficients of fecundity on length and weight indicate a greater correlation between fecundity and weight in all lakes for whitefish and trout (Table 4), whereas the opposite is generally considered to be true (Bagenal and Braun 1968). Weights used here were round weights, however, and included the weight of the ovaries, so that weight and fecundity are likely to be autocorrelated. I used the relationship between length and fecundity, therefore, in comparisons between lakes.

Average adjusted fecundity of a 45-cm whitefish from Alexie over all years was significantly greater than the average fecundity of whitefish from Chitty and Drygeese (Table 5). Baptiste whitefish had the second highest average fecundity and were significantly more fecund than Drygeese whitefish which had the lowest

TABLE 5. Fecundity of whitefish at 45-cm fork length and trout at 55-cm fork length between lakes averaged over all years.

	Alexie	Baptiste	Chitty	Drygeese
		Whitefish		
n	77	54	71	43
$\log_e$ fecundity	10.3252	10.2758	10.2077	10.1578
SE	0.0340	0.0360	0.0515	0.0458
$\bar{x}$ fecundity	30 498	29 022	27 111	25 815
		Trout		
n	38	28	53	64
$\log_e$ fecundity	7.7955	7.7914	7.7983	7.7961
SE	0.0591	0.0645	0.0446	0.0363
$\bar{x}$ fecundity	2 430	2 420	2 436	2 431

average fecundity. The average fecundity of a 55-cm trout over all years was remarkably consistent among the four lakes, ranging only 2420–2436 (Table 5). This was in spite of the significant annual changes in some lakes.

The relationships between fecundity and length for whitefish from Baptiste, Chitty, and Drygeese were very similar over the usual size range of mature fish in these lakes (Fig. 1), although the regression coefficients for the equations varied somewhat. In Alexie the larger mature fish were more fecund than in the other lakes (Fig. 1). The relationships between fecundity and length for trout from Baptiste, Alexie, and Drygeese were also very similar over the normal size range of mature fish, but the larger mature fish in Chitty were less fecund than in the other lakes (Fig. 1).

Discussion

Significant annual variations in fecundity of whitefish and/or trout occurred in all the exploited lakes but not in unexploited Baptiste Lake. The relationship between annual changes in fecundity and exploitation is not clear, however, as only three of six exploited populations showed significant and consistent increases in fecundity throughout the study. Although exploitation began in 1973, it occurred mainly in summer and early autumn. It seems unlikely that the fish could have responded to the 1st yr of exploitation by the autumn 1973 spawning. For this reason, 1972 and 1973 results may be considered pretreatment results in the exploited lakes and compared with the 1974–76 results. All the exploited whitefish populations had greater average adjusted fecundity in 1974–76 than in 1972–73, but only in Chitty Lake was the difference statistically significant (covariance analysis, $F = 9.64$, $P < 0.01$). Average adjusted fecundity of whitefish in Baptiste declined slightly between 1972–73 and 1974–76. The fecundity of trout was significantly higher in all the exploited lakes after exploitation. Average fecundity of trout was higher in Baptiste in 1974–76 than in 1972–73 but the increase was not significant (covariance analysis, $F = 0.830$, $P > 0.05$).

Proportional increase in fecundity of whitefish and trout was not directly related to exploitation. Comparing

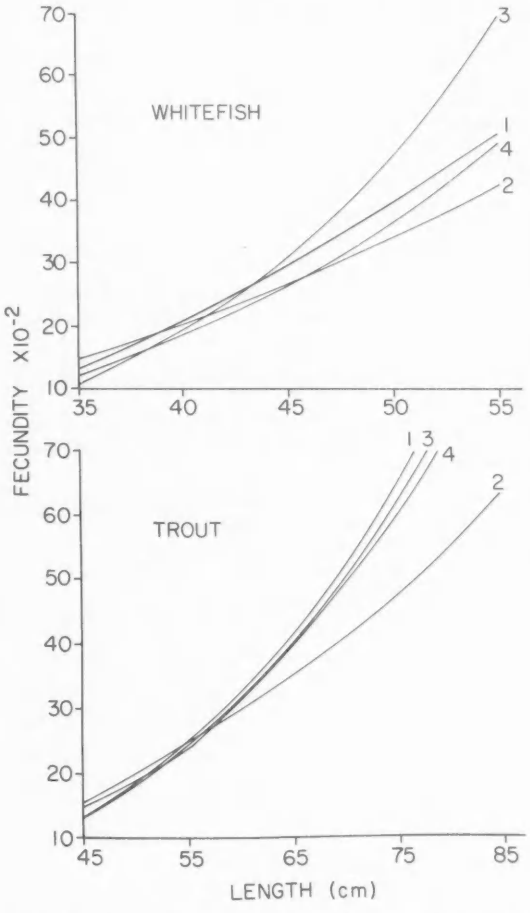

FIG. 1. Regression curves of fecundity on length for whitefish and trout in their normal mature size range. For whitefish 1 = Baptiste, fecundity (F) = $0.45L^{2.908}$; 2 = Chitty, F = $4.20L^{2.302}$; 3 = Alexie, F = $0.01L^{3.928}$; 4 = Drygeese, F = $0.19L^{3.11}$. For trout 1 = Baptiste, F = $0.011L^{3.075}$; 2 = Chitty, F = $0.34L^{2.212}$; 3 = Alexie, F = $0.010L^{3.089}$; 4 = Drygeese, F = $0.019L^{2.93}$.

average fecundity weighted by sample size for 1972–73 against 1974–76, whitefish fecundity increased 12% in Alexie, 13% in Drygeese, and 25% in Chitty. Trout fecundity increased 29% in Alexie, 44% in Chitty, and 50% in Drygeese. Increases in trout fecundity were, therefore, proportionately greater than increases in whitefish fecundity.

On the basis of more limited data, Healey and Nicol (1975) previously reported no significant difference in fecundity of whitefish between the lakes. Although significant differences were apparent in this analysis, they are small relative to the overall variation in whitefish fecundity. Greatest adjusted fecundities for whitefish in the exploited lakes (31 100–33 400) were within the observed range for the species, but were above the average curve for most lakes (Healey and Nicol 1975). The greatest adjusted fecundity for trout (3170–4090) was higher than previously recorded for this species at 55-cm fork length (Healey 1975, 1978a). The regression curves describing the relationship between length and fecundity are also well within the range of curves for the two species, (Healey and Nicol 1975; Healey 1975), and the variation from lake to lake was comparatively small. This result is not surprising as the lakes were selected for their physical and biological similarity.

It seems likely that both species responded to exploitation by an increase in individual fecundity, but sample size was too small, and the period of exploitation too brief, for this to be clearly demonstrated in the whitefish. A longer period of exploitation might have elicited a stronger response from the whitefish but it appears that variable fecundity may be a more important population-regulating mechanism in lake trout than in whitefish.

Increases in fecundity among the whitefish were apparently not linked to more rapid growth rate, and the same may be true for trout. Although young whitefish in Drygeese did grow slightly more rapidly following exploitation, there was no obvious increase in size at age among mature fish (Healey 1978b). Increased food supply for the survivors cannot be ruled out as a cause of increased fecundity in whitefish and trout, but among the whitefish there also appeared to be complicated interactions within the population similar to those hypothesized by Johnson (1976). Social interaction must, therefore, also be considered a possible cause of fecundity variations in whitefish (Healey 1978b, unpublished data).

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Acceptability of Rapeseed Proteins in Diets of Rainbow Trout (*Salmo gairdneri*)

M. YURKOWSKI, J. K. BAILEY, R. E. EVANS, JO-ANNE L. TABACHEK, G. BURTON AYLES

Department of Fisheries and the Environment, Fisheries and Marine Service, Research and Resource Services, Freshwater Institute, Winnipeg, Man. R3T 2N6

AND J. G. EALES

Department of Zoology, University of Manitoba, Winnipeg, Man. R3T 2N2

YURKOWSKI, M., J. K. BAILEY, R. E. EVANS, J.-A. L. TABACHEK, G. B. AYLES, AND J. G. EALES. 1978. Acceptability of rapeseed proteins in diets of rainbow trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 35: 951–962.

Weight gain and feed consumption results showed that rapeseed protein concentrate (RPC) and rapeseed meal (RM) can be substituted for soybean meal (SM) and perhaps partially for herring meal (HM) in rainbow trout (*Salmo gairdneri*) control (SM–HM) diet and thus have economic benefits. Rapeseed flour (RF) was a poor source of proteins due to its greater effect on thyroid function. Rapeseed proteins have little effect on liver weight, body moisture, liver and body lipid, liver and body sterol content, visual and histological appearance of liver, heart and visceral tissues, or on the flavor, but caused yellow pigmentation of the skin. The levels of individual fatty acids in the diets directly affected the levels of individual fatty acids in the liver and body, while the type and level of dietary rapeseed proteins appeared to have no effect. The levels of fatty acids, 20:1 and 22:1 (includes erucic acid), were lower in the body and even lower in the liver compared with the diets. All test diets, except RPC–HM diet, caused marked thyroid hyperplasia, believed to be due to glucosinolates (goitrogens). However, some compensation for this goitrogenic action must occur because plasma T_4 levels indicated a hypothyroid state for only five test diets (highest RPC-containing diet; highest RM-containing diet; all three RF-containing diets).

Key words: dietary rapeseed, glucosinolates, feed–gain ratios, growth, lipids, fatty acids, plasma T_4, thyroid histology, flavor, weight gain

YURKOWSKI, M., J. K. BAILEY, R. E. EVANS, J.-A. L. TABACHEK, G. B. AYLES, AND J. G. EALES. 1978. Acceptability of rapeseed proteins in diets of rainbow trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 35: 951–962.

Les résultats obtenus en gain pondéral et en consommation de nourriture démontrent que l'on peut substituer le concentré de protéines de graines de colza (RPC) et la farine de graines de colza (RM) à la farine de soya (SM) et peut-être partiellement à la farine de hareng (HM) dans le régime témoin (SM-HM) de truites arc-en-ciel (*Salmo gairdneri*), et en retirer ainsi des bénéfices économiques. A cause de son effet prononcé sur la fonction thyroïdienne, la farine de graines de colza s'avère une pauvre source de protéines. Les protéines de graines de colza affectent peu le foie, l'humidité du corps, les lipides hépatiques et corporels, la teneur en stérols hépatiques et corporels, l'aspect visuel et histologique du foie, du coeur et des tissus viscéraux, ou la saveur, mais elles causent une pigmentation jaune de la peau. Les niveaux d'acides gras individuels dans les régimes affectent directement les niveaux d'acides gras individuels dans le foie et le corps, alors que le type et le niveau de protéines de graines de colza dans le régime ne semblent pas avoir d'effet. Les niveaux d'acides gras, 20:1 et 22:1 (y compris l'acide érucique), sont inférieurs dans le corps et encore plus bas dans le foie comparativement aux niveaux dans les régimes alimentaires. Tous les régimes testés, à l'exception du régime de RPC-HM, causent une hyperplasie thyroïdienne marquée que l'on croit causée par des glucosinolates (goitrogènes). Cependant, il doit y avoir une compensation quelconque pour cette action goitrogénique, car les niveaux de T_4 plasmique indiquent une hyperthyroïdie avec seulement cinq des régimes testés (régime contenant le plus de RPC; régime contenant le plus de RM; les trois régimes contenant RF).

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FEED costs are the largest single operating cost in the commercial production of trout. The improvement of existing and development of new protein supplements are desirable for least-cost feed formulations for fish. Greater use of locally produced plant proteins as replacements for fish proteins and imported plant proteins could be desirable for economic reasons.

Rapeseed (*Brassica napus* and *B. campestris*) is a major agricultural crop in western Canada (Craig 1971). Meals of this oilseed have a high protein content, 35–45% on a dry weight basis, with an amino acid composition similar to soybean meal (Clandinin et al. 1972). However, the use of rapeseed in livestock and poultry feeds is restricted by toxic levels of glucosinolate breakdown products, erucic acid, trypsin inhibitors, phytates, phenolic compounds, and tannins (Appelqvist 1972; Fenwick and Hoggan 1976; Kozlowska et al. 1976; Lo and Hill 1972b). Canadian commercial processing of rapeseed uses moist heat to improve the quality of meal by inactivating trypsin inhibitors and myrosinase (thioglucoside glucohydrolase, E.C. 3.2.3.1), which hydrolyzes glucosinolates to toxic 5-vinyloxazolidine-2-thione (goitrin), aliphatic isothiocyanates, and aliphatic nitriles (van Etten 1969; Youngs et al. 1972). Intensive research is presently directed toward improvement of rapeseed protein by reduction or removal of these toxic compounds by genetic selection (Calhoun et al. 1975; Downey 1971; Röbbelen and Nitsch 1975) and by chemical methods (Kozlowska et al. 1972).

The purpose of this study was to evaluate commercial rapeseed meal (RM) rapeseed flour (RF) and rapeseed protein concentrate (RPC) from Bronowski variety of *Brassica napus* as a replacement for herring meal (HM) and/or soybean meal (SM) in diets fed to rainbow trout (*Salmo gairdneri*). As measures of the acceptability of these rapeseed proteins, we determined feed consumption, weight gain, feed–gain ratios, fish body and liver composition (moisture, lipids, sterols, and fatty acids), thyroid function, tissue histology, and flavor of trout fish.

Materials and Methods

RAPESEED PROTEIN SOURCES AND DIET FORMULATION

RM was prepared by heat treatment (105°C) and solvent extraction of rapeseed, the same procedures used commercially. RF was prepared by dehulling and solvent extraction, and RPC by dehulling, solvent and water (100°C) extractions, of rapeseed using established methods (Gorrill et al. 1974). Compositions of rapeseed proteins, SM, HM, and wheat middlings are given in Table 1.

A control diet (SM–HM) was prepared by using GRT1-52 diet formula (a rainbow trout grower diet developed by the Department of Nutrition, College of Biological Sciences, University of Guelph, Guelph, Ont.). A commercial diet, Ewos (Ewos trout feed, Astra Chemicals, Mississauga, Ont.), was used as an additional control. Test diets were prepared by substituting RM, RF, and RPC for herring meal and/or soybean meal in GRT1-52 control diet. The diets were pelleted without steam treatment and crumbled to the required size. The formulations and compositions of the 10 prepared diets and Ewos feed are given in Table 2.

TABLE 1. Comparison of proximate composition of protein sources. HM = herring meal; SM = soybean meal; WM = wheat middlings; RPC = rapeseed protein concentrate; RM = rapeseed meal; RF = rapeseed flour.

Proximate composition (% dry wt)[a]	Protein source					
	HM[b]	SM[c]	WM[d]	RPC	RM	RF
Crude protein (%N × 6.25)	79.9	50.5	19.5	64.8	43.0	55.4
Crude fat	9.7	1.9	4.2	8.6	5.7	4.9
Crude fiber	3.3	6.3	5.9	5.6	13.8	4.2
Ash				7.6	6.6	7.1
Nitrogen-free extract				5.7	25.8	23.6

[a]AOAC Methods (1971).
[b]Whole Canadian herring meal produced by British Columbia Packers Ltd., Vancouver, B.C.
[c]Solvent extracted meal supplied by Federated Co-operatives, Winnipeg, Man.
[d]Produced by Maple Leaf Flour Mills, Toronto, Ont.

FISH FEEDING EXPERIMENT

Feeding experiments were carried out at the Rockwood Experimental Hatchery, Gunton, Man. The stocks used were received as eyed eggs from Nisqually Trout Farm, Olympia, Wash. The experiment began July 3, 1974 and ended 23 wk later on December 10. Fish were reared in fiberglass tanks (capacity 60 L; flow rate 2.3 L/min). Water temperatures varied between 10 and 12°C but were the same for all tanks. The three replicates of the 10 dietary formulations and the commercial control were assigned to the tanks of fish at random. Initially 100 fish were placed in each tank and this number was reduced to 65 after 2 mo to prevent crowding and remained at that number. The maximum density in any of the tanks at the conclusion of the experiment was 45 g of fish/L.

The fish were raised on a commercial feed from the swim-up stage until the beginning of the experiment. They were fed a mixture of one third of the experimental formulation and two thirds of the commercial diet during the 1st wk of the experiment, and a mixture of one-half experimental and one-half commercial during the 2nd wk in order to accustom them to the change in feed. Thereafter, only experimental formulations were used.

The fish were fed manually ad libitum 4–5 times daily. Food was offered in small amounts a number of times at each feeding to minimize wastage. All fish in each tank (total weight per tank) were weighed every 2 wk. The amount of feed offered, weight gain, the feed–gain ratio (dry weight of food fed to gain in wet weight of fish), and the feed protein–gain ratio were determined for each diet.

At the beginning of the experiment, 36 fish were individually analyzed for moisture content, and six pooled samples of 6 fish each were analyzed for lipid and sterol content and fatty acid composition. At the end of the experi-

TABLE 2. Formulation and composition of diets fed to rainbow trout.

	Diets										
	Control[a] (SM–HM)	RPC–HM	RPC–SM	RPC	RM–HM	RM–SM	RM	RF–HM	RF–SM	RF	Ewos
Ingredients (% dry wt)											
Herring meal, ground (HM)	35.0	35.0	—	—	35.0	—	—	35.0	—	—	—
Soybean meal, ground (SM)	22.1	—	22.1	—	—	37.3	—	—	29.7	—	—
Rapeseed protein concentrate (RPC)	—	22.1	35.0	57.1	—	—	—	—	—	—	—
Rapeseed meal, commercial (RM)	—	—	—	—	22.1	35.0	72.3	—	—	—	—
Rapeseed flour (RF)	—	—	—	—	—	—	—	22.1	35.0	64.7	—
Wheat middlings, ground	30.4	30.4	30.4	30.4	30.4	13.7	15.2	30.4	21.3	22.2	—
Fish oil stabilized	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	—
Soybean oil[b]	—	—	—	—	—	1.5	—	—	1.5	0.6	—
Trace mineral mix[c]	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	—
Vitamin premix[d]	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	—
Choline chloride premix[e]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	—
Ascorbic acid premix[f]	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	—
Supplement premix[g]	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	—
Composition (by analysis, % dry wt)											
Crude protein (%N × 6.25)	46.4	49.7	40.7	43.4	44.4	38.7	35.2	45.8	40.2	41.0	48.8
Crude fat (ether extract)	9.4	10.6	8.9	10.8	9.2	7.7	7.0	10.2	8.7	8.7	7.5
Fat (Bligh and Dyer 1959)	10.8	12.8	10.9	11.9	10.9	8.9	8.5	12.2	10.4	11.0	8.6
Crude fiber (acid detergent method Harris 1970)	4.9	5.2	6.0	7.0	8.3	10.6	16.3	4.9	4.8	5.0	8.8
Moisture, % as fed	9.5	9.3	10.2	10.1	10.7	9.5	9.3	9.4	9.0	8.9	8.0
ω3 fatty acids	1.7	1.6	0.9	1.1	2.0	0.7	1.0	2.0	1.2	1.2	1.6
Available energy (kcal/g)[h]	3.15	3.34	3.02	3.13	3.15	2.76	2.56	3.22	3.00	3.04	3.23
Total glucosinolates (μg/g)[i]	0	100.0	158.0	257.0	223.0	354.0	730.0	223.0	354.0	654.0	—
Butenyl isothiocyanate	0	49.0	77.0	126.0	66.0	105.0	217.0	66.0	105.0	194.0	—
Pentenyl isothiocyanate	0	2.0	4.0	6.0	29.0	46.0	94.0	29.0	46.0	84.0	—
Goitrin (oxazolidinethione)	0	49.0	77.0	126.0	128.0	203.0	419.0	128.0	203.0	375.0	—
Dietary iodine (μg/g)[j]	3.5	2.7	2.1	1.9	3.8	2.6	2.7	2.2	2.2	2.0	14.5

[a]This is GRT 1-52 diet (University of Guelph).
[b]Partially hydrogenated.
[c]Trace mineral premix contained 0.446 g MnO_2, 0.021 g KI, 0.133 g Fe_2O_3, 0.042 g $CuSO_4$, 0.006 g ZnO, 0.004 g $CoCl_2$, and 99.348 g NaCl.
[d]Vitamin premix contained 0.303 g *d*-calcium pantothenate, 0.270 g pyridoxine·HCl, 0.279 g riboflavin, 2.888 g niacin, 0.046 g folic acid, 0.247 g thiamine·HCl, 0.003 g biotin, 0.110 g Vitamin B_{12} (0.1%), 0.055 g menadione bisulfite, 0.111 g BHT, 3.220 g Vitamin E (275 IU/g), 0.330 g Vitamin D_3 (20 000 IU/g), 0.100 g Vitamin A (325 000 IU/g), and carrier (wheat middlings) 92.038 g.
[e]Choline chloride premix contained 2.58 g choline chloride and 97.42 g carrier (wheat middlings).
[f]Ascorbic acid premix contained 2.76 g ascorbic acid and 97.24 g carrier (wheat middlings).
[g]Supplement premix contained 18.0 g dicalcium phosphate, 12.0 g DL-methionine, and 70.0 g carrier (wheat middlings).
[h]Protein, 3.9 kcal/g; fat, 8.0 kcal/g; nitrogen-free extract, 1.6 kcal/g (Phillips and Brockway 1959).
[i]Calculated from glucosinolate content of RPC, RM, and RF determined by the method of Youngs and Wetter (1967).
[j]Analyzed by method of Lauber (1975).

ment, three fish per replicate were individually analyzed for moisture content, and a pooled sample of three fish was analyzed for lipid and sterol content and fatty acid composition. Nine livers from each replicate were pooled and analyzed for lipid and sterol content and fatty acid composition.

The lipid contents of diets, liver, and whole fish were determined by the Bligh and Dyer (1959) method. The lipids were transesterified by heating for 90 min at 70°C in 5% methanolic HCl. About one half of the sample was used for sterol analysis and the remainder was purified (Adsorbosil-1 thin-layer plates 25 mm thick; toluene solvent) for fatty acid analysis. A gas chromatograph (Varian Aerograph, model 2100) equipped with flame ionization detector and fitted with a glass column (150 cm × 6.25 mm; 4.0 mm ID) packed with 100/120 mesh Gas-Chrom Q containing 3% OV-1 was used for the sterol analysis. The flow rates of air, helium, and hydrogen were those recommended by the manufacturer. The injector, column, and detector temperatures were 280, 235, and 280°C respectively. Peak areas were measured by an electronic integrator (model CRS-101; Infotronics Corp., Houston, Tex.). Percent sterol is calculated by dividing total area of sterol peaks times 100 by total area of all peaks in the transesterified lipids. A gas chromatograph (Varian Aerograph, model 1200) equipped with a stainless steel column (180 cm × 3.17 mm OD) packed with 100/120 mesh Gas-Chrom P containing 10% EGSS-X was used for fatty acid analysis. The injector, column, and detector temperatures were 240, 160, and 240°C, respectively. Peak areas were measured as above and fatty acid composition was calculated as weight percent.

At the end of the experiment, the trout were anesthetized with isothermal 2-phenoxyethanol and bled from the caudal blood vessels with preheparinized tuberculin syringes. The plasma was separated by centrifugation and stored at −20°C. Plasma T_4 levels were measured on freshly thawed plasma samples by radioimmunoassay (RIA) (Brown and Eales 1977). The assay detection limit was 15 ng/dL.

The results of the feeding experiment were subjected to a one-way analysis of variance (Snedecor and Cochran 1967). Duncan's new multiple range test (Steel and Torrie 1960) was used to test the significance of the differences between individual means.

Nine fish per replicate were grossly examined for external appearance, presence of body lesions, abnormalities of eyes and fins, and for abnormalities of liver, kidney, visceral fat cells, and heart. The liver, heart, and the floor of the mouth along with portions of the first four gill arches (thyroid) were removed from each fish and fixed in Bouin's

TABLE 3. Initial weight, feed consumed, weight gain, and feed conversion (feed–gain ratio) of rainbow trout fed experimental diets and a commercial feed. Different superscript capital letters of column values denote significant differences between these values ($P < 0.05$).

Diet	Initial wt[a] (g)	Feed fed[b] (g)	Wt gain[c] (g)	Feed:gain[b]	Feed protein:gain[b]
GRT 1-52 (SM–HM)	4.37	31.12^{EF}	28.12^{F}	1.11^{AB}	0.51^{AB}
RPC-HM	3.96	33.16^{FG}	34.93^{G}	0.95^{A}	0.47^{A}
RPC–SM	4.41	27.17^{CD}	20.47^{D}	1.33^{D}	0.54^{B}
RPC	4.51	23.97^{A}	17.24^{C}	1.39^{D}	0.61^{C}
RM–HM	4.46	33.10^{FG}	29.02^{F}	1.14^{BC}	0.51^{AB}
RM–SM[d]	4.35	29.40^{DE}	19.15^{D} (15.07)	1.54^{D} (1.95)	0.76^{E}
RM	4.45	29.05^{CDE}	15.57^{BC}	1.87^{E}	0.66^{CD}
RF–HM	4.36	30.50^{E}	25.45^{E}	1.20^{C}	0.55^{B}
RF–SM	4.48	26.92^{BC}	15.92^{BC}	1.69^{E}	0.68^{C}
RF	4.45	24.12^{AB}	11.62^{A}	2.07^{F}	0.85^{F}
Ewos	4.58	34.58^{G}	33.75^{G}	1.02^{A}	0.50^{AB}
ANOVA	$P > 0.10$	$P < 0.001$	$P < 0.001$	$P < 0.001$	$P < 0.00$
SE	0.127	1.090	0.945	0.039	0.019

[a]Mean of three replicates (100 fish per replicate).
[b]Mean of three replicates.
[c]Mean of three replicates (65 fish per replicate).
[d]One half of the supplement premix (dicalcium phosphate and DL-methionine) was accidentally omitted from this diet. New values for weight gain and feed–gain ratios were calculated by the method that is used when a data cell is missing in a randomized block experiment (Snedecor and Cochran 1967). Old values are in parentheses.

solution. After washing for 2 d in 70% ethanol, the tissues were decalcified for 3 d in 70% ethanol containing 3% HCl. Tissues were then washed in 70% alcohol for 24 h and embedded in paraffin. Tissue sections were cut at 10 μm and stained with Harris' hematoxylin and eosin. Two fish were also examined after only 2-mo feeding on diets RF–SM and RF.

Flavor Analysis

The flavor of fish fed RM–HM, RM, and RPC–HM diets was compared with the flavor of those fed the control diet (SM–HM) through a paired comparison preference test (ASTM 1968). Each pair consisted of a sample fed the SM–HM diet and a sample fed one of the experimental diets. Judges were given three different pairs and asked to select the sample preferred from each pair. Differences between samples in each pair were evaluated with a standard table of choices for paired comparison testing.

Results

Feed Consumption and Growth

The best weight gain, feed–gain ratios, and feed protein–gain ratios of rainbow trout fed various diets were obtained with RPC–HM diet and Ewos feed (Table 3). Fish fed these diets had significantly ($P < 0.05$) higher weight gains than the control (SM–HM) diet and RM–HM diet and lower feed–gain ratios than RM–HM diet. In comparing diets containing RPC with the corresponding diets containing RM or RF, feed consumption was similar or greater with RM, and similar or lower with RF, than with RPC. Feed consumption was similar or higher with RPC than with RF. It was significantly higher with RM than with RF. Weight gains were similar or higher with RPC than with RM, and RM and RPC were higher than with RF. Therefore, significantly lower feed–gain ratios were obtained with RPC than with RM, which was significantly lower than with RF. Protein–gain ratios and (protein plus fat)–gain ratios gave relatively similar results.

The accidental omission of one half of the supplement premix in RM–SM diet is a probable cause of the low weight gain and a high feed–gain ratio in trout fed that diet.

Moisture, Lipid, and Sterol Content of Fish

Preexperimental fish fed Ewos feed and those on RF diet had similar moisture contents, which were slightly, but significantly higher than those on the other diets (Table 4). Fish on diets containing rapeseed protein, either alone or with SM, tended to be higher in moisture content than those on diets containing rapeseed protein plus HM.

Trout fed RPC–HM diet, RM–HM diet, and Ewos feed contained significantly more lipid than those fed the control (SM–HM) diet and significantly less lipid than those fed the RF–HM diet (Table 4). Fish on RF–SM diet had significantly more lipid than those on RPC–SM diet, which had a higher content (only on a wet weight basis) than those on RM–SM diet. Fish fed RPC diet contained more lipid than those fed RM diet, which contained more than those fed RF diet. Pre-

TABLE 4. Body moisture content, body and liver lipid and sterol content, liver weight, and plasma T_4 level of trout fed experimental diets and a commercial feed (mean values). Different superscript letters of column values denote significant differences between these values ($P < 0.05$); n indicates the number of fish of each diet analyzed for blood plasma T_4.

Diet	Whole fish				Liver			Blood plasma	
	Moisture (%)	Lipid (% wet wt)	Lipid (% dry wt)	Sterols (% lipids)	% whole fish (wet wt)	Lipids (% wet wt)	Sterols (% lipids)	T_4 (ng/dL)	n
Preexperimental									
Ewos	77.9	4.77	21.5	5.8					
Experimental									
GRT 1-52 (SM–HM)	75.8^{BCD}	5.76^{BC}	23.8^{ABCD}	3.0^{AB}	1.20^{AB}	4.59^{BCD}	9.0^{A}	147^{E}	9
RPC–HM	74.9^{AB}	6.66^{DE}	26.5^{DEF}	2.9^{A}	1.22^{ABC}	4.29^{BC}	10.1^{BCD}	71^{BCD}	14
RPC–SM	75.5^{AB}	6.25^{CD}	25.5^{BCDE}	3.3^{ABC}	1.16^{A}	4.21^{BC}	11.2^{EF}	143^{E}	14
RPC	75.7^{BCD}	7.18^{EF}	29.9^{G}	3.0^{AB}	1.34^{D}	4.58^{BCD}	11.3^{F}	26^{AB}	10
RM–HM	75.0^{AB}	6.70^{DE}	26.8^{EF}	3.1^{ABC}	1.29^{BCD}	5.17^{D}	10.1^{BCD}	84^{CD}	14
RM–SM	76.6^{D}	5.47^{AB}	23.4^{AB}	4.0^{D}	1.19^{AB}	4.75^{BCD}	9.4^{AB}	98^{DE}	14
RM	76.1^{CD}	5.95^{BC}	24.9^{ABCD}	3.6^{CD}	1.31^{CD}	4.68^{BCD}	10.2^{BCDE}	38^{ABC}	13
RF–HM	74.3^{A}	7.67^{F}	29.9^{G}	3.3^{ABC}	1.20^{AB}	4.80^{CD}	10.5^{CDEF}	15^{A}	9
RF–SM	75.1^{ABC}	7.10^{E}	28.9^{FG}	3.5^{BCD}	1.33^{D}	4.09^{AB}	9.6^{ABC}	15^{A}	10
RF	77.9^{E}	4.81^{A}	21.8^{A}	4.7^{E}	1.34^{D}	4.57^{BCD}	10.2^{BCDE}	28^{AB}	10
Ewos	74.8^{AB}	6.77^{DE}	26.9^{EF}	2.8^{A}	1.71^{E}	3.42^{A}	11.1^{DEF}	149^{E}	10
ANOVA	$P < 0.001$	$P < 0.05$	$P < 0.01$	$P < 0.01$	$P < 0.001$	$P < 0.01$	$P < 0.05$		
SE	0.46	0.315	1.34	0.28	0.045	0.326	0.050		

experimental trout and those on RF diet had the lowest lipid contents (wet and dry basis).

The lipid content of the liver from rainbow trout fed most diets was not significantly different (Table 4). Fish fed Ewos feed had the lowest lipid content.

Feeding various diets to trout resulted in statistically significant differences in the sterol content in the lipids of trout and their liver, but the differences were relatively small (Table 4).

FATTY ACID COMPOSITION OF FISH AND DIETS

Fatty acid compositions of diets, whole bodies, and livers of trout were compiled into plant protein (PP) dietary group (RPC–SM, RPC, RM–SM, RM, RF–SM, and RF diets) and plant–fish protein (PFP) dietary group (control (SM–HM), RPC–HM, RM–HM, and RF–HM diets and Ewos feed) (Table 5). Results within each group were similar, while the results between the two groups were different. Thus, RPC, RM, and RF in the diets fed to trout have a similar effect on the fatty acid composition of trout and their liver, but differences between PFP dietary group and PP dietary group are due only to differences in the dietary fatty acid composition.

The diets, trout body, and trout liver from PFP group of diets had a higher level of total saturated acids, 16:0 (except in the liver), total ω3 acids, and 22:6ω3, but a lower level of total monoenoic acids, 18:1, total ω6 acids, and 18:2ω6 than in the PP group of diets, respectively (Table 5). However, in the diet and liver within the two groups, the levels of total acids of saturated, monoenoic, ω6, and ω3 acid groups and some individual fatty acids were similar. The exceptions of the individual acids were that higher levels of 16:1, 18:1 (only in the PFP dietary group), and 22:6ω3, and lower levels of 20:1, 22:1, and 20:5ω3 occurred in trout body. Comparison of liver with the diet and trout body within each group showed that higher levels of total saturated, 16:0, 20:4ω6, total ω3 acids, and 22:6ω3, and lower levels of total monoenoic acids, 16:1, 18:1, 20:1, 22:1, total ω6 acids, 18:2ω6, 18:3ω3, and 18:4ω3 occurred in trout liver.

FLAVOR, APPEARANCE, AND HISTOLOGY

Results of flavor comparisons indicated that there were no flavor differences among fish fed RM–HM, RM, RPC–HM, and control (SM–HM) diets.

Pigmentation differences were observed in trout fed various diets. Control fish had a normal and silvery pigmentation. Experimental fish tended to be darker and had a distinct silvery pigmentation. Fish fed diets containing rapeseed proteins with HM approached normal coloration, having a slight yellowish pigmentation and dark violet markings. Yellow pigmentation is due to carotenoids present in rapeseed protein (Froehling et al. 1972).

Livers of fish fed unsupplemented rapeseed protein diets had similar weights, but were significantly larger than those on the other diets (Table 4). Decreasing the amount of rapeseed protein in the diet tended to reduce the size of the liver.

Mortality of trout on all diets was negligible.

TABLE 5. Comparison of fatty acid composition of diets, bodies, and livers of trout within and between the plant fish protein (PFP) dietary group and plant protein (PP) dietary group.

Fatty acids[a]	PFP dietary group[b]			PP dietary group[c]		
	Diet	Whole body	Liver	Diet	Whole body	Liver
14:0	4.2±0.8	4.1±0.3	1.8±0.1	1.7±0.1	2.1±0.2	1.2±0.1
16:0	15.1±0.8	15.5±0.6	17.1±0.5	11.4±0.4	12.5±0.2	17.8±0.3
18:0	2.3±0.3	2.6±0.2	2.7±0.3	2.5±0.2	2.4±0.5	2.5±0.2
20:0	—	0.3±0.0	0.8±0.1	—	0.8±0.0	2.0±0.1
Total	21.6	22.5	22.4	15.6	17.8	23.5
16:1	5.1±0.2	8.2±0.5	4.8±0.4	3.3±0.2	6.3±0.4	4.4±0.2
18:1	19.4±0.9	25.0±1.1	13.2±0.7	30.0±0.8	31.0±0.8	17.2±0.7
20:1	7.4±0.9	5.1±0.4	2.0±0.1	7.6±0.6	5.1±0.4	2.0±0.2
22:1	10.3±0.9	3.8±0.3	0.6±0.1	8.0±0.1	2.7±0.3	0.5±0.0
Total	42.2	42.1	20.6	48.9	45.1	24.1
18:2ω6	11.9±0.7	11.0±0.5	4.1±0.2	19.5±1.0	16.4±0.6	7.4±0.2
18:3ω6	—	0.2±0.0	0.1±0.0	—	1.1±0.1	0.4±0.0
20:2ω6	—	0.4±0.1	0.4±0.0	—	0.6±0.1	0.6±0.1
20:4ω6	—	0.8±0.0	2.8±0.1	—	1.0±0.0	4.4±0.1
22:5ω6	—	0.3±0.0	0.4±0.1	—	0.2±0.0	0.6±0.1
Total	11.9	12.7	8.8	19.5	19.3	13.4
18:3ω3	2.5±0.1	1.7±0.3	0.5±0.1	4.2±0.4	2.5±0.3	0.7±0.1
18:4ω3	1.7±0.3	1.3±0.2	0.2±0.0	1.0±0.2	1.8±0.2	0.4±0.1
20:5ω3	6.3±0.6	3.3±0.4	5.4±0.4	3.9±0.3	2.2±0.2	3.8±0.5
22:5ω3	—	0.6±0.0	0.6±0.0	—	0.4±0.0	0.6±0.1
22:6ω3	8.9±0.6	12.7±0.4	39.5±0.7	3.2±0.3	8.2±0.3	31.3±0.6
Total	19.4	19.6	46.2	12.3	15.1	36.8
ω3, % diet	1.8±0.9			1.0±0.1		
ω6, % diet	0.9			1.8		

[a]Other minor fatty acids were not included.
[b]Mean ± SE of RM–SM, RM, RPC–SM, RPC, RF–SM, and RF diets.
[c]Mean ± SE of SM–HM, RM–HM, RPC–HM, and RF diets, and Ewos feed.

There appeared to be no differences in the gross or histological appearance of liver, heart, visceral tissue, or flesh.

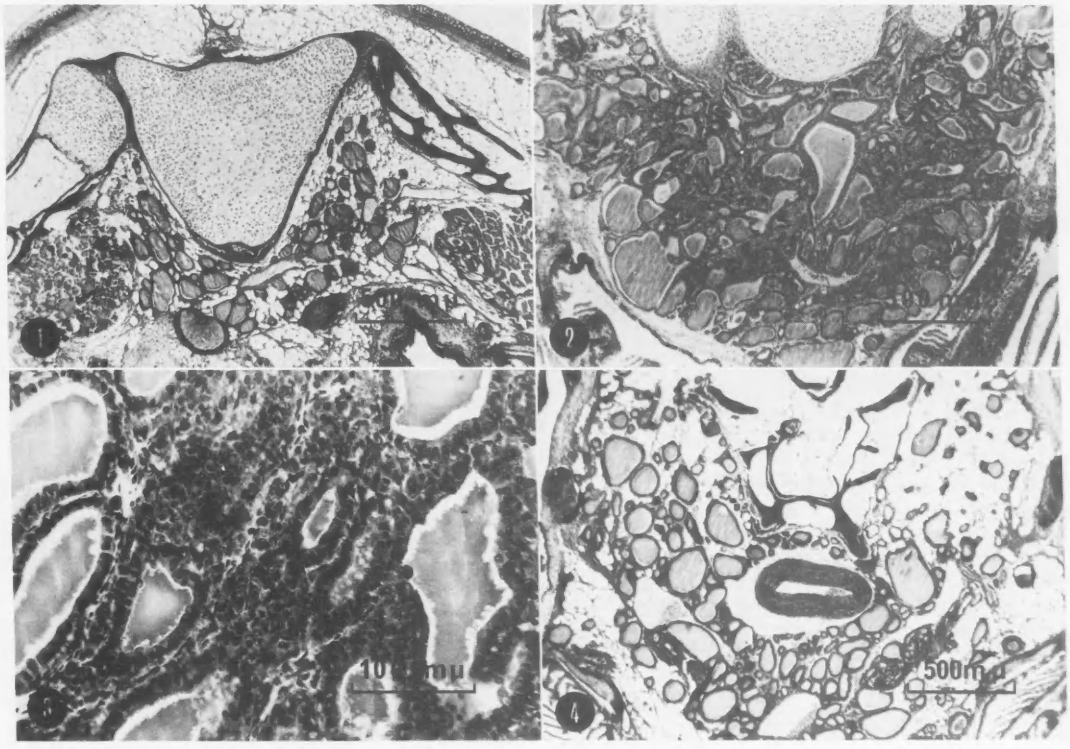
THYROID FUNCTION

The two fish examined after 2 mo on the RF–SM and RF diets showed a histologically active thyroid. Follicle cells were high columnar with nuclei containing prominent nucleoli. Irregular-shaped follicles were present, including many of small size and without colloid. Colloid was generally scant and eroded. Many mitoses were evident among the follicle cells. The total area occupied by the gland between the arches was still relatively small.

After 5 mo thyroids from fish fed the control diets (SM–HM and Ewos) were normal (Fig. 1) and similar to those described for rainbow trout by Gaylord and Marsh (1912). However, thyroids from fish fed all the other diets (except diet RPC–HM) were extremely hyperplastic with cell hypertrophy (Fig. 2 and 3), giving the gland a packed appearance. Thyroid follicles invaded surrounding bone, muscle, and connective tissues, in some instances causing their degeneration. Follicle size and shape were variable but in general follicles were smaller and more irregular than for control fish. Colloid was typically granular, eroded, and in some samples scant. In relation to controls the stained colloid was generally pink rather than red. Follicle cell nuclei were slightly increased in size, showing a tendency to occupy the basal to mid-regions of the cells, nucleoli were more prominent, and mitotic figures were numerous.

Thyroids from fish fed RPC–HM diet resembled the control fish and did not exhibit the pronounced hypertrophy and hyperplasia (Fig. 4). A few follicles had invaded bone spaces and connective tissue but no tissue degeneration was observed. The follicles were oval or spherical and ranged in size from small to medium. Colloid varied in texture, within and between thyroids in these groups, being smooth and nongranular, red and cracked or granular, and eroded with pink staining properties. No follicles were observed without colloid. Nuclei were centrally located in the cells and nucleoli were prominent. Mitotic activity was not as evident as in the more hyperplastic glands.

Plasma T_4 levels are shown in relation to concentrations of dietary glucosinolate in Tables 2 and 4 and



FIGURES 1–4. Rainbow trout thyroid transverse section.

FIG. 1. After 5 mo on the control (SM–HM) diet. Hematoxylin and eosin (H&E), 10 μm thickness. FIG. 2. After 5 mo on RPC–SM diet. Note cell hypertrophy, variable follicle size and shape, and general packed appearance. H&E, 10 μm thickness. FIG. 3. After 5 mo on the RF diet. Note the cell hypertrophy, variable follicle size and shape, eroded colloid and prominent nucleoli. H&E, 10 μm thickness. FIG. 4. After 5 mo on the RPC-HM diet. Note that cellular hypertrophy is not so pronounced and the more regular shape of the follicles. H&E, 10 μm thickness.

Fig. 5. Control fish (Ewos and SM-HM diets) had plasma T_4 levels similar to those recorded previously for rainbow trout of this size (Brown and Eales 1977).

For trout fed the three diets containing RPC, marked depression of plasma T_4 occurred only at the highest glucosinolate concentration (RPC diet). In view of the normal histological appearance of the thyroids of trout fed RPC–HM diet, it seems unlikely that the somewhat lower level of plasma T_4 in this group represents a hypothyroid state. On the other hand, the normal plasma T_4 in trout fed the RPC–SM diet indicates that the hyperplastic thyroid of these fish is capable of maintaining a normal level of plasma T_4.

For trout fed RM–HM diet and RM–SM diet, plasma T_4 levels tended to be lower than for the controls. However, moderately higher levels of T_4 were present and this indicates that despite some interference with thyroid function, the thyroid was still able to produce moderate amounts of T_4. At the highest concentration of glucosinolate (RM diet) the fish were distinctly hypothyroid as judged by plasma T_4.

For trout fed the three diets containing RF, T_4 production was greatly depressed; most plasma T_4 levels were comparable with the detection limit for the assay.

Discussion

FEED CONSUMPTION AND GROWTH

According to weight gains, feed–gain ratios, and feed protein–gain ratios, RPC is an equivalent or superior protein source to RM; RF was the poorest. RPC and RM, but not RF, may replace SM in the trout diets, but cannot totally replace HM.

RM-containing diets have a lower protein and caloric content than the respective diets containing RPC or

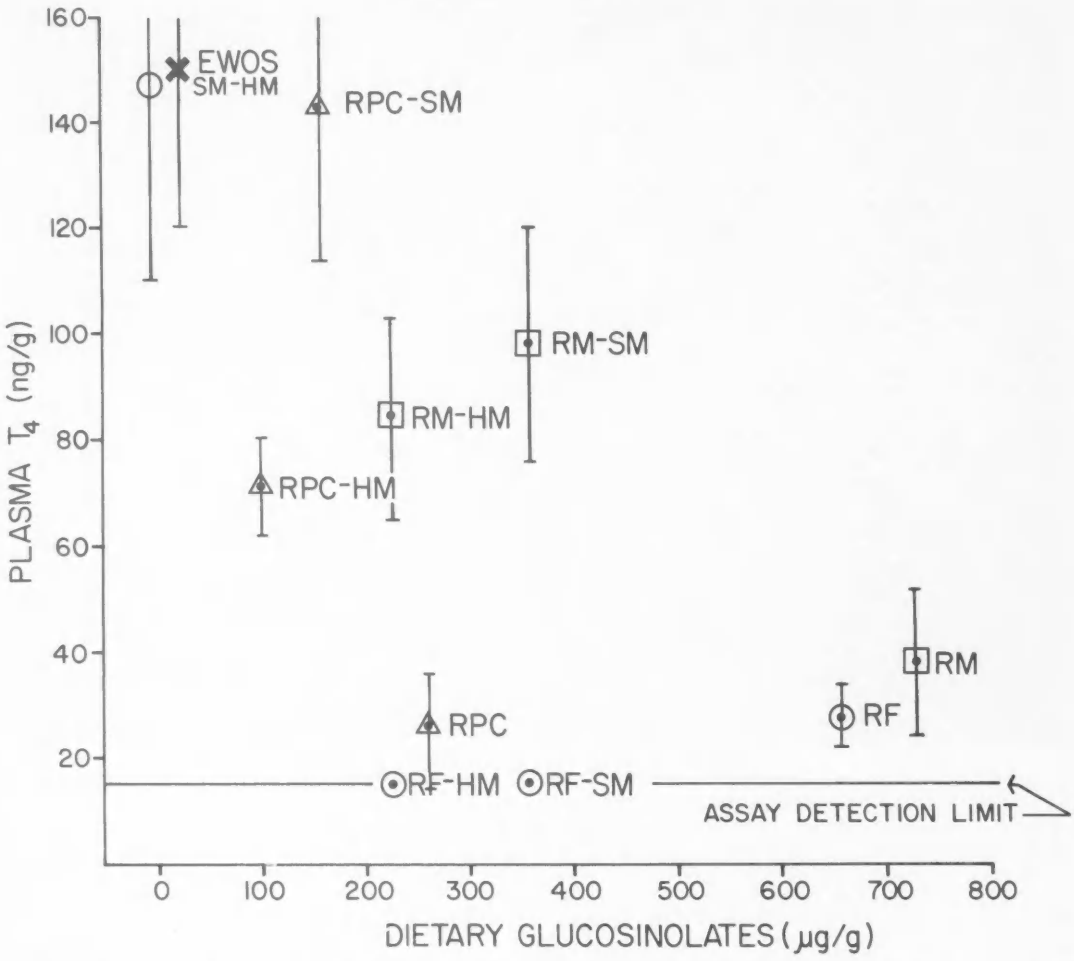


FIG. 5. Relationship between plasma thyroxine (T_4) levels and glucosinolate levels in the diets of trout fed for 5 mo on control diets (Ewos (X); SM–HM (○)) and RF (⊙), RPC (△), or RM (⊡) containing diets.

RF (Table 2). With isocaloric and isonitrogeneous diets, the trout weight gain differences could be less between respective RM- and RPC-containing diets and greater between respective RM- and RF-containing diets.

Performance characteristics of rapeseed protein in diets can be attributed to their processing. Processing consisted of hull removal from RF and RPC, heat treatment of RPC and RM, and water extraction of RPC. The presence of nondigestible hulls in RM reduced the nutrient density of the diets and hence increased the feed–gain ratios, but feed protein–gain ratios remained low. The better weight gains and feed–gain ratios in diets containing RPC and RM may be partially attributed to heat treatment. Similar studies have shown that heat treatment of dietary rapeseed meals improved the performance of rats and mice (Gorrill et al. 1974; Josefsson and Munck 1972). It was reported that heat treatment of rapeseed proteins resulted in better digestibility due to denaturation of proteins and trypsin inhibitors (Josefsson and Munck 1972; Kakade et al. 1973). In addition, heat treatment improved the growth of animals by myrosinase inactivation which reduced the level of toxic glucosinolate breakdown products and by suppression of aliphatic cyanide formation to a greater extent than the less potent growth inhibitors, aliphatic isothiocyanates and goitrin, during digestion of rapeseed proteins (Josefsson

1975; Srivastava et al. 1975; van Etten et al. 1966, 1969; Lo and Hill 1972b). Poorer growth rate in trout fed diets containing non-heat-treated RF can be attributed to these factors. Growth of rats fed diets containing RPC was better than on diets containing heat-treated RF and poorest on diets containing RF (Ballester et al. 1973; Gorrill et al. 1974).

The better weight gain and feed–gain ratios obtained with diets containing RPC may also be partially due to water extraction in preparation of RPC. Water extraction removed non-amino acid nitrogen (15%) (Agren and Eklund 1972; Lo and Hill 1972a), water-soluble mucopolysaccharides (Lo and Hill 1972a; Siddiqui et al. 1973), glucosinolates and their breakdown products (Table 1; Ballester et al. 1973), tannins, and other phenolic compounds (bitter flavor) (Kozlowska et al. 1976; Lo and Hill 1972a). Removal of phenolic compounds did not appear to alter the palatability, since diets containing RF and RPC were consumed equally well even though RPC was bland and RF or RM were bitter. Water washing of RF increased feed digestibility in rats (Ballester et al. 1973; Gorrill et al. 1974). Water washing increased the phytic acid level in rapeseed proteins (van Etten et al. 1966), which could cause mineral imbalance, such as zinc deficiency (Shah et al. 1976), if not properly supplemented.

The improved performance of trout fed RPC, RM, and RF diets supplemented with HM, and to a lesser extent with SM, over the corresponding diets with no supplementation (Table 3) can be attributed to improved essential amino acid, mineral, and vitamin balance (Clandinin et al. 1972; Bragg 1974; NRC Subcommittee on Fish Nutrition 1975). Pigs fed rapeseed proteins plus SM diets had higher nitrogen retentions and weight gains and lower feed–gain ratios, especially at heavier weight classes, than with either rapeseed proteins or SM alone in the diet (Omole and Bowland 1974a, b). The presence of rapeseed protein and SM in the diets complemented each other because SM contained more lysine and less methionine than the rapeseed proteins (Clandinin et al. 1972). Further studies should be done on the optimum trout dietary levels of commercial RM and RPC (glucosinolates completely removed) from low glucosinolate and low erucic acid commercial varieties of rapeseed, e.g. Tower.

Moisture, Lipid, and Sterol Content of Fish

Moisture and lipid content in trout on all diets was not much different, except those on RF diet had the lowest lipid content and highest moisture content. The sum of the lipid and moisture content on all diets was 81.6–82.8% (Table 4), indicating lipid–moisture relationship (Love 1970).

Trout liver lipid levels tended to follow the dietary lipid levels (Tables 2 and 4). Dietary rapeseed proteins did not have an effect on the liver lipid content. However, higher liver lipid content occurred in rats on RF diet than on RPC diet (Gorrill et al. 1974).

Fatty Acid Composition of Diets and Fish

Fatty acid composition of the diets was similar within each dietary group (PP and PFP), but was different between the two groups (Table 5). The difference between the diets of the two groups is brought about by the fatty acid composition of HM in the PFP group. Results suggest that the dietary fatty acid composition influences the fatty acid composition of the whole trout and trout liver. However, rapeseed proteins and their toxic constituents apparently had no effect.

The diets contained 8% 20:1 and 8–10% 22:1 (including erucic acid) (Table 5), which were derived from rapeseed proteins, HM, and fish oil as indicated by our analysis. The level of 20:1, and to a greater extent 22:1, was lower in the bodies and even lower in the livers of trout than that found in the diets. The level of 20:1 was greater than the level of 22:1 in the trout and their liver, opposite to that found in the diet. This was previously observed in trout (Astorg 1976) and other domestic animals (Bowland and Newell 1974; Kramer et al. 1975; Walker 1972; Vogtmann and Clandinin 1974). Since all diets contained similar levels of 20:1 and 22:1, the growth rate effect, if any, should be similar in all trout. However, further studies should be done on deleterious effects of high levels of long-chain monoenoic acids and the ability of fish to reduce the levels of these acids in their flesh.

Levels of ω3 acids in the diets may have an effect on the growth of rainbow trout. The minimum requirement for ω3 acids in rainbow trout to support optimum growth is 1% of diet (Castell et al. 1972). The PP group contained 1.0% ω3 acids and 1.8% ω6 acids and the PFP group contained 1.8% ω3 acids and 0.9% ω6 acids of the diet (Table 5). Levels present in the diet probably met ω3 acid requirements and may not have had a significant effect on weight gains obtained (Table 3).

Thyroid Function

Extremely low plasma T_4 levels and extreme thyroid hyperplasia were observed for five rapeseed protein diets (RPC, RM, RF–HM, RF–SM, and RF diets). Clearly, thyroid hormone production was markedly if not completely inhibited. Influences of rapeseed diets on thyroid function have been demonstrated in mammals and birds. Reported effects include thyroid enlargement (Clandinin et al. 1966; Lo and Hill 1971a, b; Oliver et al. 1971; Belzile et al. 1974), reduced synthesis of intrathyroidal iodocompounds (Lo and Hill 1971b), reduced levels of plasma protein-bound iodine (PBI) or thyroxine (T_4) (Manns et al. 1963; Lo and Hill 1971b; Huth et al. 1974; Bowland 1975), reduced T_4 degradation (Münchmeyer et al. 1974), and increased binding of T_4 to serum albumin (Lo and Hill 1971a). In most cases, these effects have been attributed to isothiocyanates and goitrin, formed from glucosinolates in the feed by myrosinase enzyme (van Etten et al. 1966).

However, it may be incorrect to assume that glucosinolates account for all the variation in plasma T_4 between fish fed the various diets. Diets were not isocaloric and also differed in protein content and quality as well as other respects, and effects of this type cannot be excluded. For example, Higgs and Eales (1978) have shown that different caloric and nutrient intakes have a pronounced effect on T_4 kinetics and conversion of T_4 to T_3 in brook trout (*Salvelinus fontinalis*).

On the basis of the final body weights, a correlation apparently exists between thyroid function and growth. Weight gain was particularly poor in the RPC, RM, RF–SM, and RF diet groups. Although higher in the RF–HM diet group, weight gain was lower than for fish on RM–HM diet or RPC–HM diet. The relationship between thyroid function and growth in fish is incompletely understood. However, recent studies indicate that thyroid hormones in conjunction with other hormones may enhance growth of salmonids (Narayansingh and Eales 1975; Donaldson et al. 1978).

All the rapeseed diets with the exception of RPC–HM diet induced marked thyroid hyperplasia indicative of goitrogen activity. However, only RPC, RM, RF–HM, RF–SM, and RF diets caused marked depression of plasma T_4. Thus plasma T_4 levels are particularly informative in evaluating thyroidal status. Observations based on the histological appearance do not provide a valid index of thyroid activity, as even some of the seemingly histopathological thyroids were able to maintain a moderately high plasma T_4 level.

For any given glucosinolate concentration, the form (RPC, RM, or RF) in which the rapeseed protein was added to the diet appeared to have an effect on glucosinolate toxicity. For example, the RPC, RM–HM, and RF–HM diets had approximately the same levels of glucosinolates. While plasma T_4 was reduced to low levels by RF–HM and RPC diets, the RM–HM diet did not reduce plasma T_4 greatly. The lesser toxicity of glucosinolates in the three RM diets as opposed to the three RPC diets and the three RF diets is presumably due to more effective destruction of myrosinase by heat treatment of RM. However, at high concentrations even the feed with inactivated myrosinase (diet RM) will cause a marked inhibition of the trout thyroid function.

From the data available it is not possible to speculate on the way in which glucosinolates or possibly other rapeseed ingredients interfere with the trout thyroid function. They may act on the thyroid directly or could influence the peripheral metabolism of the thyroid hormones. However, since all of the rapeseed diets had similar iodine levels (Table 2) and all fish were maintained on the same water supply, alterations in iodine availability could not likely have confounded interpretations of thyroidal status due to rapeseed constituents.

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Elevated Heavy Metals: A Stress on a Population of White Suckers, *Catostomus commersoni*, in Hamell Lake, Saskatchewan

G. A. McFarlane and W. G. Franzin

Department of Fisheries and the Environment, Fisheries and Marine Service, Freshwater Institute, Winnipeg, Man. R3T 2N6

McFarlane, G. A., and W. G. Franzin. 1978. Elevated heavy metals: a stress on a population of white suckers, *Catostomus commersoni*, in Hamell Lake, Saskatchewan. J. Fish. Res. Board Can. 35: 963–970.

This study examined populations of white suckers (*Catostomus commersoni*), in two physically and chemically similar lakes in the vicinity of, and receiving heavy-metal fallout from, a base-metal smelter complex near Flin Flon, Manitoba. The white suckers occupying Hamell Lake, Saskatchewan, which is contaminated by Zn, Cu, and Cd, showed signs typical of a population under stress when compared with the population in Thompson Lake, Manitoba, which contains much lower levels of these metals. Hamell Lake white suckers showed greatly increased growth in length and weight, increased fecundity, and earlier age of maturation, but reduced spawning success, reduced larval and egg survival, smaller egg size, and reduced longevity compared with Thompson Lake white suckers. We attribute these differences to elevated heavy metals in Hamell Lake waters, particularly in early spring, a most critical period in the reproductive cycle of these fish. Effects of the metals on other species of fish in Hamell Lake are also discussed.

Key words: heavy metals, fish, population, stress, white sucker

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Les auteurs examinent dans cette étude des populations de meuniers noirs (*Catostomus commersoni*) dans deux lacs physiquement et chimiquement identiques du voisinage d'un complexe de fonderies de métaux de base près de Flin Flon, Manitoba, et qui reçoivent des retombées de métaux lourds de ce complexe. Les meuniers noirs occupant le lac Hamell, Saskatchewan, contaminé par Zn, Cu et Cd, montrent les symptômes typiques d'une population soumis à un stress, comparativement à la population du lac Thompson, Manitoba, qui contient des niveaux beaucoup plus bas le ces métaux. Les meuniers noirs du lac Hamell accusent une croissance en longueur et en poids considérablement accrue, une plus grande fécondité et un âge de maturité plus jeune, mais un succès de reproduction moindre, une survie réduite des larves et des oeufs, une taille d'oeufs moindre et une durée de vie réduite, comparativement aux meuniers noirs du lac Thompson. Les auteurs attribuent ces différences à une teneur élevée de métaux lourds dans les eaux du lac Hamell, surtout au début du printemps, période des plus critiques dans le cycle reproducteur de ces poissons. Ils examinent également les effets des métaux sur d'autres espèces de poissons dans le lac Hamell.

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Accumulation of heavy metals in aquatic ecosystems may lead to complex changes in the structure and stability of these systems. Many studies have been conducted on the effects of specific heavy metals on phytoplankton and zooplankton (Klass et al. 1974; Biesinger and Christensen 1972) and on fish (Benoit et al. 1976; Bengtsson 1974a, b, c; Eaton 1974; Pickering and Gast 1972; Brungs 1969; Pickering 1968), but many of the reports on the effects of specific heavy metals, particularly Zn and Cd, on fish are conflicting. Brungs (1969) observed a decreased growth rate for the fathead minnow, *Pimephales promelas*, and Bengtsson (1974c) found decreased growth of the minnow *Phoxinus phoxinus* after exposure to elevated zinc levels. However, Pickering (1968) reported that low concentrations of zinc had a stimulating effect on the growth of the bluegill, *Lepomis macrochirus*.

Eaton (1974) found no effects on survival, development, or reproduction of adult bluegills at Cd levels of 31 μg/L, while Pickering and Gast (1972) observed a small reduction in hatching success among eggs exposed to 57 μg/L Cd. In contrast, Bengtsson et al. (1975) observed vertebral damage in the minnow *Phoxinus* at 7.5

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μg/L Cd and Benoit et al. (1976) reported chronic cadmium toxicity to brook trout, *Salvelinus fontinalis*, at 3.4 μg/L.

Clearly, responses of fishes to specific heavy metals vary considerably as do responses to different water quality within one species. There is limited information on the effects to fishes of mixtures of these metals. Eaton (1973) in a chronic toxicity test using a Zn–Cu–Cd mixture found the Zn in the mixture was no more toxic than alone, Cu toxicity was enhanced, and Cd toxicity in the trimetal mixture was reduced. In lakes containing up to 90 μg/L Zn and 10 μg/L Cu, the fish, which included the white sucker, did not appear to be adversely affected by these heavy-metal concentrations (Van Loon and Beamish 1977).

Most of the preceding studies have been laboratory studies involving only one toxicant at a time and very controlled conditions. There is little known on the effects of heavy-metal accumulation and toxicity on fish populations in natural aquatic ecosystems. The purpose of this study was to determine whether elevated heavy-metal levels, particularly Zn and Cd, found in natural lakes had any observable effects on populations of the white sucker, *Catostomus commersoni*, a common but relatively unexploited species.

Materials and Methods

Study Area

The Flin Flon area, situated on the Manitoba–Saskatchewan border at ~55°N, 102°W, was selected for study because lakes in the area receive high levels of heavy-metal deposition (Van Loon and Beamish 1977), originating from a base-metal smelter located in the city of Flin Flon. This smelter produces zinc, copper, cadmium, and smaller quantities of gold, silver, selenium, and tellurium (Sabina 1972). The smelter has been in production since 1930, and a new super stack has been in operation since November 1974. Hamell Lake, Sask., and Thompson Lake, Man., were chosen for this study because preliminary examination had shown them to be very similar physically and chemically except that Hamell Lake receives a heavier loading of smelter emissions. Hamell Lake is situated ~5 km northwest of the smelter stack, while Thompson Lake lies ~20 km east of the smelter (Fig. 1). During the sampling period, Hamell Lake was downwind of the smelter 17.8% of measurable wind hours, while Thompson Lake was downwind 7.6% of the time. Annual loading of smelter emissions to the surfaces of Hamell and Thompson lakes for the period August 1, 1976 to August 1, 1977 was as follows: Zn 812, 119, Cu 173, 5.4, and Cd, 2.5, 0.4 mg/m², respectively. Although Cu is a major constituent of atmospheric fallout near the smelter, the water levels of Cu in Hamell Lake are similar to levels in other lakes in the area. Physical features of these two lakes are compared as follows:

	Hamell Lake	Thompson Lake
Surface area (m^2)	2.33×10^6	2.20×10^6
Max depth (m)	6	12
Mean depth (m)	2.56	4.10
Vol (m^3)	5.22×10^6	8.53×10^6

Water Sampling and Analysis

Water samples were collected, preserved, and analyzed according to the methods outlined by Beamish et al. (1975). Heavy metals were determined by flameless atomic absorption, at the Freshwater Institute heavy-metals laboratory. Samples were taken at 1-m intervals from surface to bottom in Hamell Lake and at 2-m intervals in Thompson Lake. Water samples were collected bimonthly from June 1976 to June 1977. Five samples of surface waters, in addition to the bimonthly samples, were collected at different times from various parts of each of the lakes to assess horizontal variation of metal concentrations in the lakes.

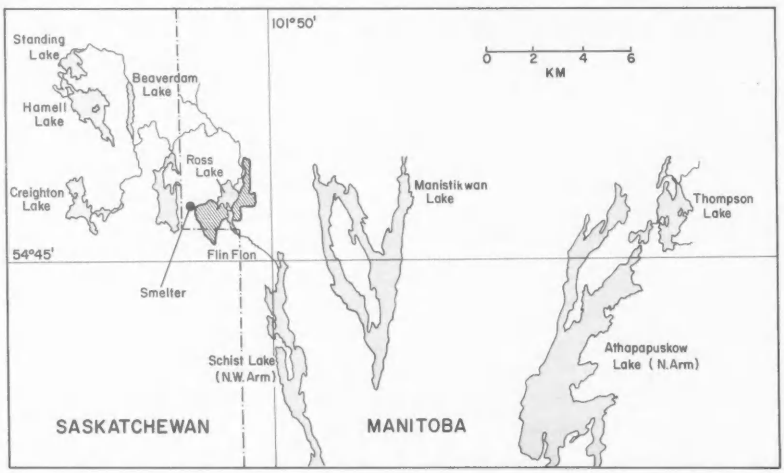

FIG. 1. Study area near Flin Flon, Man.

United States Environmental Protection Agency (EPA) trace-metal standards were submitted to analysts as blind samples along with water samples 4 times during the study period. Laboratory accuracy on three determinations of duplicate samples of Environmental Protection Agency Reference Sample No. 2 and 3 was as follows: Zn, ±9%; Cu, ±6.9%; and Cd, ±11.5%.

Laboratory precision of analysis of duplicate EPA samples and triplicate lake-water samples was as follows: Zn, ±6.7%; Cu, ±7.7%; and Cd, ±2.1%.

Fish Study Methods

Populations of white sucker in Hamell and Thompson lakes were sampled extensively from May through August 1976 and during May and June 1977. All fish were captured with gill nets of 19–115 mm stretched mesh and small-mesh trap nets (Beamish 1973a). White suckers captured from both lakes during the spawning run in May 1976 were tagged and released for future recapture and age verification. The tagging procedure was carried out while the fish were anesthetized with tricaine (MS-222®) and fish were tagged with Floy spaghetti tags. Fork length, weight, sex, and maturity were recorded, and the first 3 or 4 rays of the left pectoral fin were taken from all fish. Eighteen and 23 ripe female white suckers were removed from Hamell and Thompson lakes, respectively, and their ovaries excised and preserved in Gilson's solution for fecundity studies. Egg counts were made by the method described by Healey and Nicol (1975). Both lakes were fished for 1 d in both mid-June (1976) and mid-July (1976), to check on maturity of females. A minimum of six female suckers were collected each time from each lake. In August 1976 both lakes were fished extensively for five nights with a full range of gill nets (19–115 mm stretched mesh), and fork length, weight, sex, and maturity were recorded and pectoral fin rays taken. In May and June 1977 sex and maturity were recorded from captured fish. Small-mesh gill nets (19 and 25 mm stretched mesh) were fished in early June 1977 for young 1976-spawned white suckers. Recaptured fish were sampled and the first 3 or 4 rays from the previously untouched pectoral fin were removed for age verification. Ages of all fish were obtained by the method described by Beamish (1973b). Ages were verified by capturing 1976-tagged white suckers from both lakes in May 1977 and aging by the untouched pectoral fin. Of the six fish recaptured and aged in 1977 all were aged at 1 yr older than in 1976. Numbers of northern pike (*Esox lucius*), walleye (*Stizostedion vitreum vitreum*), lake whitefish (*Coregonus clupeaformis*), and yellow perch (*Perca flavescens*) captured throughout the study were recorded.

Results

Water Chemistry

The chemical environments of Hamell and Thompson lakes are compared in Tables 1 and 2. The major cations and pH in the lakes are similar, while SO_4, Cl, and heavy metals show marked differences. The highest metal concentrations were recorded in early spring, immediately under the ice after the snowmelt had passed through. Values for Hamell Lake in 1976 and 1977 were as follows: Zn 1160, 734, Cu 27, 16, and Cd 4.6, 5.3 μg/L, respectively. These values persisted until spring turnover and diminished gradually as mixing occurred. Samples taken from the surface waters at different locations on the lake gave similar concentrations to those found at routine sampling stations.

Fishing

Despite chemical and physical similarities other than heavy-metal concentrations our evaluation of the white sucker populations in Hamell and Thompson lakes revealed a number of distinct differences.

1) *Growth* — In August 1976 gill nets fished simultaneously in Hamell and Thompson lakes caught 94 and 175 white suckers, respectively. Analyses of these catches indicated the following differences. Growth of suckers in terms of length is similar until age 2 but after that point Hamell Lake white suckers begin and continue to grow faster than Thompson Lake suckers (Fig. 2). Covariance analysis of the regressions (Fig. 3) of length on age for the white suckers in both lakes revealed that they had significantly different slopes ($F = 26.7$ at 1, 265 df; $P < 0.05$); i.e. at a given age the adult Hamell Lake suckers are much longer than those found in Thompson Lake.

Table 1. Chemical parameters of Hamell and Thompson lakes. Values are annual means (mg/L) of bimonthly samples for the water column for June 1976–June 1977.

Lake	pH	SO_4	Cl	Na	K	Mg	Ca
Hamell	7.3	15.02	3.54	1.52	1.39	3.09	15.55
Thompson	7.5	7.65	1.14	1.94	1.23	4.31	16.02

Table 2. Concentrations of heavy metals in Hamell and Thompson lakes. Values are annual means (μg/L) of bimonthly samples for the water column for June 1976–June 1977. Ranges of means in parentheses.

	Mn		Fe		Cu		Cd		Zn	
Lake	Total	Filtered	Total	Filtered	Total	Filtered	Total	Filtered	Total	Filtered
Hamell	30	9.4	58.8	38.8	13 (10–20)	13 (8–17)	0.6 (0.2–1.1)	0.5 (0.1–1.1)	245 (141–341)	211 (107–327)
Thompson	114	93.1	110	68.8	15 (9–18)	14 (8–16)	0.1 (0.1–0.4)	0.1 (0.1–0.4)	20 (5–38)	14 (4–27)

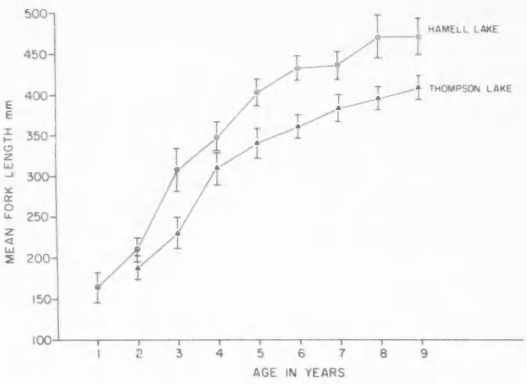

FIG. 2. Growth curves of mean fork length on age for Hamell and Thompson Lake white suckers. Vertical lines represent standard deviations of means.

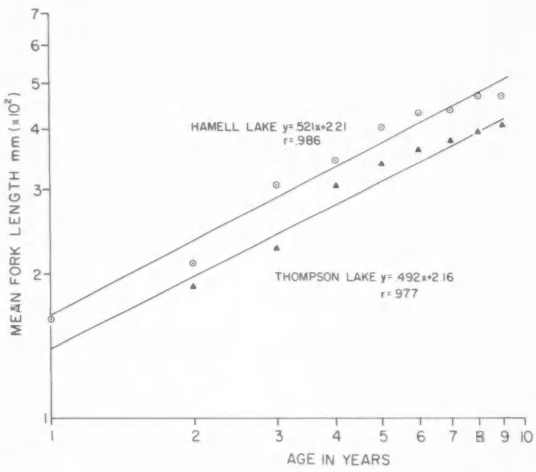

FIG. 3. Regressions of $\log_{10}$ mean fork length on age for Hamell and Thompson Lake white suckers.

The mean ages for Hamell Lake and Thompson Lake white suckers are 4.27 and 6.22 yr, respectively. The *t*-test for difference of means shows that this age difference is highly significant ($0.025 < P < 0.05$). In Hamell Lake during August no white suckers older than 9 yr were caught; however, four 10-yr-olds, five 11-yr-olds, one 12-yr-old, and one 13-yr-old were captured in Thompson Lake at this time. These results coupled with the significantly lower mean age of Hamell Lake white suckers suggest a reduced longevity of Hamell Lake white suckers.

The regressions of length–weight relationships can be expressed in the following equations:

Hamell Lake	$\log_{10}$ wt = 3.12 $\log_{10}$ length −5.10;
Thompson Lake	$\log_{10}$ wt = 3.18 $\log_{10}$ length −5.30.

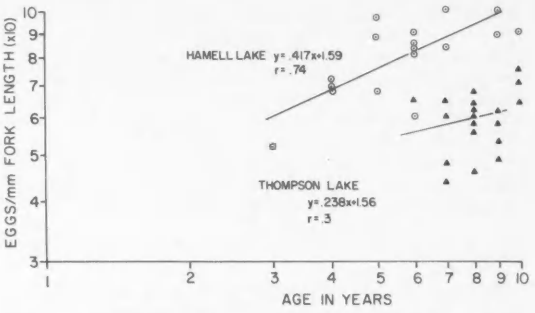

FIG. 4. Fecundity in terms of $\log_{10}$ eggs/mm fork length on $\log_{10}$ age of Hamell and Thompson Lake white suckers.

Covariance analysis of the weight on length relationship of white suckers in the two lakes revealed that the regression coefficients for the two populations were not significantly different, but the elevation of the regression lines were significantly different ($F = 218.04$ at 1, 266 df; $P < 0.005$). This indicates that Hamell Lake suckers achieve and maintain a consistently greater weight at a given length throughout adult life than Thompson Lake suckers; i.e. in this case there is no increasing factor as there is in length. Thus we might assume they maintain a relatively similar condition throughout life in the two lakes.

2) *Fecundity and spawning success* — The fecundity of white suckers in Hamell Lake was higher than in Thompson Lake (Fig. 4). Covariance analysis of the number of eggs per millimetre of fork length on age revealed that the regression coefficients were significantly different at the 5% level ($F = 4.146$ at 1, 37 df).

The mean egg diameter of Hamell Lake white suckers was 1.74 ± 0.12 mm and for Thompson Lake 1.82 ± 0.09 mm. A *t*-test for difference in mean egg diameter between populations showed that the difference is significant ($0.025 < P > 0.010$).

During the 3rd and 4th wk of May and the 1st wk of June 1976, white suckers were captured on the spawning beds in both lakes. Sixty-one females were captured in Hamell Lake and 245 females in Thompson Lake. Hamell Lake females were maturing at an earlier age (Fig. 5): 3- and 4-yr-old females captured appeared ripe and the majority of spawners were 5–7 yr old. The youngest spawning females captured in Thompson Lake were 5 yr old and the majority were 7 and 8. Almost all males captured in both lakes during this time were ripe and running. The percentage of females at the various stages of maturity are presented in Fig. 6. Subsequent examination in the 3rd wk of June and 3rd wk of July 1976 indicated that 100% of the Thompson Lake females captured were spent but that in Hamell Lake most females caught had not spawned at all, the ovaries were enlarged, and the eggs were soft-shelled and pale, indicating that they were being resorbed.

3) *Catch per unit effort* — Catch per unit effort (CPUE) for white sucker populations in Hamell and Thompson lakes calculated from a five-night fishing period were

	Gill net (m^2)	Hours	No. fish	CPUE
Hamell Lake	139.35	349.2	94	0.00193
Thompson Lake	176.50	246.8	175	0.00397

Catch per unit effort equals the number of fish caught divided by the number of square metres of net fished times the number of hours fished. Nets were set consecutively in the two lakes by the same personnel using the same type and mesh size of gill nets, so that CPUE values are considered reliable and the difference between Hamell and Thompson lakes is not the result of inefficient or different fishing practices. The age-frequency histograms and sex ratios for our catches in both lakes (Fig. 7) indicate that the populations were normally distributed for age and sex.

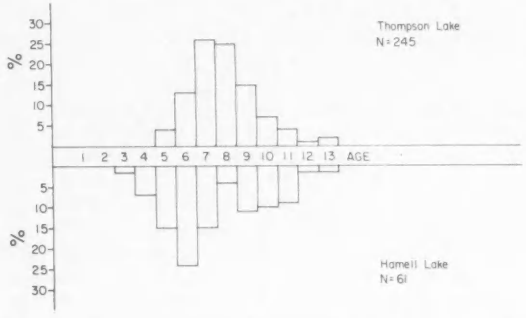

FIG. 5. Frequency histogram of percent female white sucker spawners at each age for Hamell and Thompson lakes.

4) *Mortality* — As mortality rates can only be calculated for the straight parts of the catch curve (Ricker 1975), only the older age-classes can be compared, i.e. the 8- and 9-yr-olds. The annual mortality rates between these age-groups in Hamell and Thompson lakes are 0.817 and 0.790, respectively. This comparison shows that the older fish in the lakes have similar mortality rates. However, catch-per-unit-effort data indicate a much smaller population in Hamell Lake. Visual observation of females throughout the summer of 1976 has shown that there was at least 50% reproductive failure in Hamell Lake females, suggesting considerable prenatal mortality. In June 1977 small-mesh gill nets (25 mm stretched mesh) were fished in both lakes in an attempt to catch 1976-spawned suckers — one 30-m, 25-mm-mesh net captured 25 1-yr-old suckers in Thompson Lake, while a 270-m, 25-mm-mesh net captured 9 1-yr-olds in Hamell Lake. This suggests that mortality in Hamell Lake occurs very early in life, either prenatally or in early larval stages.

Discussion

A random sample of adult Hamell Lake white suckers would suggest a healthy population living in optimal conditions, i.e. increased growth rate, early maturation,

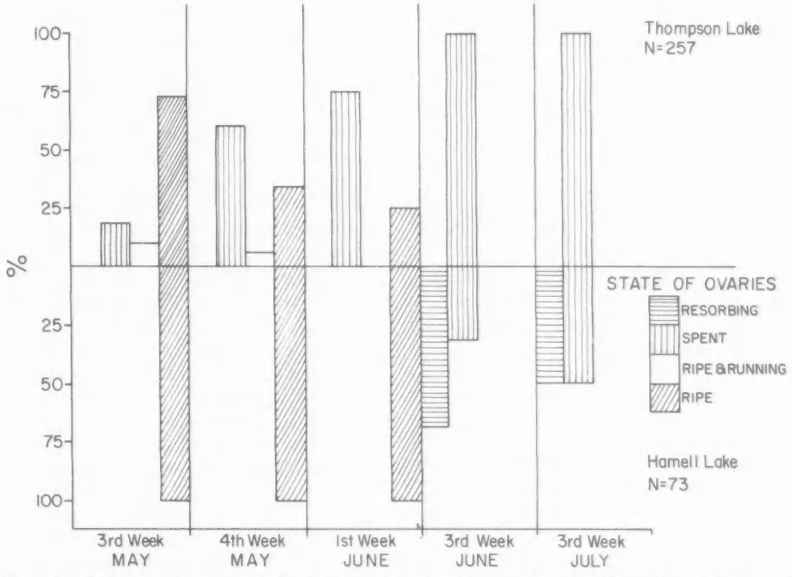

FIG. 6. Reproductive status of spawning female white suckers in Hamell and Thompson lakes, May to July 1976, determined by state of ovaries.

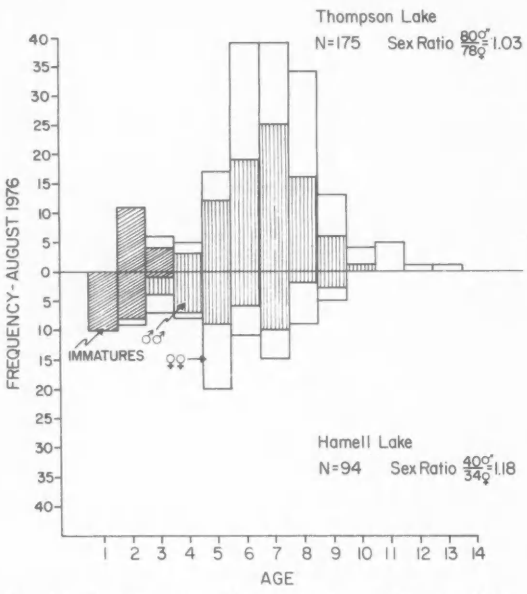

FIG. 7. Age-frequency histogram of random population samples of Hamell and Thompson Lake white suckers.

and increased fecundity. However, when the low catch per unit effort, reduced spawning success, reduced longevity, and reduced egg size are taken into account, all these features are indicative of a population under stress.

Relating specific toxicants to specific responses in a natural population is extremely difficult. Our data indicate that the white sucker population in Hamell Lake has responded to elevated levels of heavy metals (Table 2), particularly Zn and Cd, both known toxicants to fish. At least 50% of the mature female white suckers in our samples of the Hamell Lake population did not spawn and in all probability there was reduced spawning in the rest. This agrees well with many laboratory observations on the effect of heavy metals on numbers of eggs produced per female (Brungs 1969; Bengtsson 1974b; Eaton 1973); however, the problem in comparing laboratory studies with field studies is well known (Brungs et al. 1976; Van Loon and Beamish 1977). The mean concentrations of Zn in Hamell Lake are near the top of the laboratory-tested ranges and in early spring are well above these ranges. Cadmium concentrations in the spring were higher than concentrations known to be chronically toxic to some species (Benoit et al. 1976). Final egg development and spawning occurred in Hamell Lake during the time at which the highest yearly metal levels are recorded; the reduced spawning success of the white suckers is probably a result of the toxic actions of the elevated Zn and Cd levels. Mn and Fe values, although higher in Thompson Lake than in Hamell Lake waters, are well within the values commonly found (Hutchinson 1957). Surficial sediment concentrations of Mn and Fe in both lakes are similar (unpublished data). The difference in water concentrations of these elements in the two lakes is probably due to differences in dissolved organic matter (Hutchinson 1957). The higher concentrations found in Thompson Lake are well below concentrations reported to be harmful to aquatic organisms (McKee and Wolf 1963). Effects on fishes at these low levels are unknown.

The extremely low catch per unit effort of 1-yr-old fish in Hamell Lake when compared with Thompson Lake suggests that there is an increase in early larval mortality. Although there is no direct evidence of increased fry mortality, the levels of toxic metals to which the eggs and newly hatched fry were exposed are well above those known to adversely affect fry (Skidmore 1965; Brungs 1969; Bengtsson 1974b). Our observations of water quality in the lake in all seasons of the year showed that major life-support parameters, e.g. O_2, pH, and temperature, remained within the ranges adequate for support of fish life.

Nicholson (1957) showed that if stress increases the mortality rate of individuals making up a specific age-class, compensatory adjustments in reproductive rates and mortality rates of other age-classes will result in an increase in the proportion of individuals in the age-class immediately preceding the one most directly stressed. Reduced spawning success and increased larval mortality indicate that the eggs and the young are the age-group most severely stressed. Accordingly, the compensatory adjustment to be expected, and the one we observe, for suckers in Hamell Lake is increased fecundity (Fig. 4).

On the basis of short-term studies Pickering (1968) and G. J. Farmer and S. Ray (personal communication) reported increased growth in the presence of elevated Zn levels, while Brungs (1969) and Bengtsson (1974c) report a decrease in growth at concentrations of Zn lower than those found in Hamell Lake. These studies have not shown whether these growth patterns occur over the entire life cycle of a fish or whether they are compensated for in later life. C. B. Lane (unpublished data) reported that Hamell Lake had a poor bottom fauna. Therefore we might expect that the sucker population would be composed of perhaps small, slow-growing individuals, not, as is the case, large, fast-growing fish. This suggests that food supply is not a problem for white suckers in Hamell Lake. The increased growth rate is associated with early maturation, compensating for the decrease in recruitment of young fish to the population probably brought about by reduced spawning success and apparent increased larval mortality. The low catch per unit effort in Hamell Lake suggests that compensatory adjustments are failing to overcome the effects of heavy-metal stress.

Effects on Other Fishes

In late summer and early fall 1973 600 m of gillnet set overnight in Hamell Lake captured eight walleye ranging in age from 4 to 10 yr (R. J. Beamish personal communication). Intensive fishing in spring and summer of 1976 with gill nets and trap nets captured only two walleye and two lake whitefish. One of the walleye was aged at 3 yr, the rest of the fish were older. C. B. Lane (unpublished data) reports that walleye, whitefish, and lake herring (*Coregonus artedii*) were captured in 1965 and suggested a small (454 kg) whitefish fishery be established. This fishery was never initiated. No lake herring have been captured since at least 1973 and there has been a very definite decline in walleye and lake whitefish populations since 1973, which corresponds to an increase in heavy-metal levels in the lake for this period. Apparently walleye and whitefish populations are more sensitive to heavy-metal stress, and the eventual loss of these species may result from direct long-term lethal effects as well as a failure to recruit young fish. The white sucker population in Hamell Lake shows reduced recruitment and longevity (Fig. 7), which appears to be the result of long-term exposure to heavy metals. The small numbers of other species captured in Hamell Lake would suggest that these species are being affected similarly by heavy metals.

Immigration

In spring 1977 many white suckers were captured in Hamell Lake that were generally smaller than the resident population and that were actively spawning. At this time walleye and whitefish were also captured (60 m of gill net set overnight captured six walleye and five whitefish). It was found that a beaver dam on the outlet of Hamell Lake, which had been intact and impassable to fish for the previous 3 yr, had been completely destroyed. Several hundred white suckers were observed entering the lake at this point and probably the walleye and lake whitefish had entered the lake in this way. The fish were apparently immigrating into Hamell Lake through a small, shallow lake, Standing Lake, from Beaverdam Lake. A tagging study on these species conducted by Hudson's Bay Mining and Smelting Company staff biologists in 1974, 1975, and 1976 has shown that in the spring these fish can move from Schist Lake to Beaverdam Lake (R. Bridges personal communication). Access by fish to Schist Lake from many uncontaminated lakes is unimpeded, and white suckers have shown their capability to migrate long distances (unpublished data). Therefore, fish migrating into Hamell Lake in spring of 1977 could have come from as far as 40 km away.

At the present time the outlet from Hamell is again completely blocked by the beaver dam. The walleye and lake whitefish that entered Hamell Lake will probably die off over the next few years, providing the dam is not destroyed again. The immigrant white suckers, we suggest, will again show all the signs of stress we have observed in the current resident white sucker population.

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Diel Food Selection by Two Sizes of Rainbow Trout (*Salmo gairdneri*) in an Experimental Stream

PETER A. BISSON

Weyerhaeuser Company, Longview, Wash. 98632, USA

BISSON, P. A. 1978. Diel food selection by two sizes of rainbow trout (*Salmo gairdneri*) in an experimental stream. J. Fish. Res. Board Can. 35: 971–975.

The food selected by small (~3 g) and large (~45 g) hatchery rainbow trout (*Salmo gairdneri*), studied over a 28-h period, showed that the fish fed selectively, but often on different prey organisms. Feeding activity was highest during daylight hours but was only loosely associated with increases in invertebrate drift density. The majority of large trout exploited adult chironomids on the surface, whereas small trout fed primarily on midwater drift. At night when drift densities were low the limited feeding that took place apparently shifted to bottom foraging. Prey size was the most important factor affecting vulnerability to predation at all hours. Both large and small fish rarely consumed invertebrates <2 mm long. Selection of larger individuals among certain prey taxa occurred, and in two important groups (Trichoptera and Chironomidae) large trout ate significantly larger prey than did small trout. By being size selective, the trout lost the opportunity to exploit smaller organisms, particularly Collembola, which constituted the bulk of the total drift.

Key words: diel habits, drift, predation, rainbow trout, size selection

BISSON, P. A. 1978. Diel food selection by two sizes of rainbow trout (*Salmo gairdneri*) in an experimental stream. J. Fish. Res. Board Can. 35: 971–975.

Les habitudes alimentaires de petites (~3 g) et de grandes (~45 g) truites arc-en-ciel (*Salmo gairdneri*) de pisciculture ont été étudiées sur une période de 28 h. Les truites des deux tailles exercent un choix dans leur nourriture et on observe une grande variation dans la sélection des proies parmi les membres de chaque groupe. L'alimentation se poursuit plus activement pendant les heures de clarté, mais elle n'est que vaguement associée à des augmentations de densité des invertébrés en dérive. La plupart des grandes truites se nourrissent de chironomidés adultes à la surface, alors que les petites truites se nourrissent surtout d'organismes dérivant entre deux eaux. La nuit, quand la densité des organismes dérivants est faible, le peu d'alimentation qui se produit consiste à fourrager sur le fond. A toute heure, la taille des proies est le facteur qui influe le plus sur la vulnérabilité à la prédation. Les grandes truites, tout comme les petites, consomment rarement des invertébrés de longueur <2 mm. Il se fait un choix de grands individus parmi certains taxons de proies, et dans deux groupes importants (Tricoptera et Chironomidae), les grandes truites mangent un nombre nettement supérieur de grosses proies que ne le font les petites truites. En exerçant un choix de taille, les truites ne profitent pas de l'occasion d'utiliser les petits organismes, en particulier Collembola, qui constituent la majeure partie de la dérive totale.

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STREAM-DWELLING salmonid fishes are believed to feed selectively (Allen 1941; Hynes 1970; Waters 1972), but the basis of selection is not well understood. Studies of lake-dwelling salmonids, which actively search for food, have shown prey size, visibility, and relative abundance to be important factors influencing predation intensity on different prey species. In streams, however, where trout often adopt stationary territories and intercept prey passing downstream in the drift, the determinants of diet and the relationship between food availability and feeding activity remain controversial. Maciolek and Needham (1952), Elliot (1967, 1970), and Metz (1974) showed increased feeding rates to be associated with increased invertebrate drift, while Chaston (1969), Tusa (1969), Mundie (1969, 1971), and Bisson (1976) found that a poor correlation often existed between the abundance of potential prey organisms and their utilization by drift feeders. Further, the relative importance of drift feeding and bottom foraging varies greatly among different populations, seasonally and with time of day (Allen 1969) as well as age of fish (Waters 1972). The existence of food selection has been questioned by Egglishaw (1967), who suggested that instances of apparent selectivity may be governed by the type of habitat in which fish feed and

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by the localized distributions of benthic organisms.

In early spring 1976 I studied the changes in diel food selection by two sizes of rainbow trout (*Salmo gairdneri*) in a spring-fed experimental stream. The objectives of the experiment were to establish whether or not the trout were feeding selectively from available food organisms, and to trace patterns in feeding activity as related to food abundance over a diel cycle.

Materials and Methods

The study was conducted in a single riffle-pool unit of an experimental stream channel located near the Kalama River in southwestern Washington. Surface areas of the riffle and pool were 13.0 and 3.7 m^2, respectively. Flow was 1.5 $m^3 \cdot min^{-1}$ and velocity over the riffle was 54 $cm \cdot s^{-1}$. Water temperature remained at 6°C throughout the diel cycle.

The experiment began at 0800 on 11 March 1976 and ended at 1200 on the following day. Sunset occurred at 1801 and sunrise was at 0620. Light levels exceeded 16 000 lx around midday and dropped below 0.1 lx at night. The stream water was very clear (<0.2 FTU) and visual detection of prey by trout during daylight was hindered neither by low light levels nor by excessive turbidity.

Rainbow trout were obtained from a commercial trout farm; the mean wet weight of "large" fish was 45.40 g (SD = 10.67) and the mean wet weight of "small" fish was 2.82 g(SD = 0.66). All fish were acclimated to the experimental stream for 1 mo prior to the study. They appeared to be well adapted to the stream and to exhibit high growth rates during their preliminary residence. Two days before the experiment the trout were removed from the stream and placed in holding tanks where they were deprived of food. At 6°C this time was sufficient for nearly complete gastric evacuation (Windell et al. 1976). During the experiment five individuals of each size were placed in the stream and allowed to feed for 4 h; they were then collected by electrofishing and replaced with 10 new, unfed fish. Immediately after recovery each trout was anesthetized and its stomach thoroughly flushed with water injected through the mouth with a blunted hypodermic needle. The stomach contents of each fish were retained separately. With the exception of turbellarians and oligochaetes, food organisms were usually intact and in excellent condition. The trout were weighed immediately following removal of stomach contents.

Drift samples were taken for 5 min at hourly intervals within each feeding period. The 210-μm mesh nylon drift net spanned the width of the stream at the downstream end of the riffle and extended several centimetres above the water to capture winged adults and terrestrial organisms floating on the surface. At the end of a 4-h feeding period, drift samples were combined to give an average estimate of the abundance of drifting invertebrates. All samples were sorted manually under magnification and lengths of specimens were determined to the nearest 0.5 mm. Biomasses of various taxa were computed with the aid of known length–weight relationships (R. N. Thut unpublished data) and results of drift sampling were expressed as drift densities (micrograms dry weight per cubic metre) passing the downstream end of the riffle and entering the pool in which most of the trout resided.

TABLE 1. Diel variation in invertebrate drift density and trout feeding intensity, which was calculated according to the formula of Manzer (1976), where feeding intensity = (total food weight ÷ estimated body dry weight) × 100.

Time interval	Drift density $\mu g \cdot m^{-3}$	Mean feeding intensity	
		Small trout	Large trout
0800–1200	12570	0.79	0.39
1200–1600	15096	0.72	0.19
1600–2000	3557	0.59	0.06
2000–2400	3027	0.21	0.04
2400–0400	7434	0.12	0.02
0400–0800	4751	0.37	0.13
0800–1200	14040	0.25	0.24

Results

The density of drifting invertebrates varied widely over the day and night (Table 1). In contrast to many natural streams, total drift density in the experimental stream was much higher at midday than it was at dusk, night, or dawn. It was not surprising, therefore, to find that trout feeding activity was highest during the day (Table 1), although the correlation between feeding intensity and drift density was not significant ($r = +0.54$ for large fish and $+0.17$ for small fish). One reason for the poor correlation was that proportionately more feeding relative to drift density took place at dusk and dawn, particularly among small trout. A second reason was that the abundance of certain preferred food organisms in the drift did not always follow the pattern of total density over the diel cycle.

Frequencies of various invertebrate taxa in trout stomachs, when compared with frequencies of those taxa in the drift (Table 2), indicated that both sizes of trout fed selectively. In general, individuals tended to favor only a few taxa during a 4-h interval. Considerable differences existed not only between large and small trout, but also between the food habits of fish within size-groups — a factor that made generalization difficult.

Collembola (mostly *Isotoma subaequalis*) and Chironomidae dominated the midday drift (0800–1600); all other taxa made up only 7% by weight of the total drift density. Very few Collembola were eaten by small and large trout, which instead relied heavily on other organisms. Small trout often preferred chironomid larvae and caddisfly larvae (*Rhyacophila* spp.), which were observed in the midwater drift and on or next to the bottom. Ovipositing and emerging chironomid adults made up the majority of food of most large trout, thus indicating that large fish had been exploiting the surface drift to a much greater extent than had the smaller trout. Neveu and Thibault (1977) have recently documented a similar increase in surface feeding by older members of a stream-dwelling brown trout (*S. trutta*) population.

TABLE 2. Changes in the mean relative frequencies (% by weight) of the most important invertebrate taxa in drift samples (D), and in stomach contents of small (S) and large (L) trout during 4-h intervals throughout one 28-h period.

Organisms	0800–1200			1200–1600			1600–2000			2000–2400			2400–0400			0400–0800			0800–1200		
	D	S	L	D	S	L	D	S	L	D	S	L	D	S	L	D	S	L	D	S	L
Turbellaria	1	0	1	1	3	0	4	10	27	10	15	17	25	36	8	28	0	41	3	0	0
Oligochaeta	1	0	0	1	4	1	6	4	2	3	0	0	2	0	0	2	0	0	1	8	1
Gastropoda	2	0	2	1	5	0	1	6	9	0	24	79	5	28	40	3	35	19	1	0	0
Ostracoda	1	1	0	1	1	1	3	1	1	3	3	1	2	7	1	3	7	2	1	0	1
Collembola	77	1	1	72	0	0	62	0	1	47	0	0	46	0	0	25	0	0	82	0	0
Ephemeroptera	1	0	0	1	16	3	1	11	2	3	28	0	1	0	2	2	0	0	1	10	2
Trichoptera	1	33	5	1	11	4	2	14	19	2	7	3	1	6	45	4	24	27	2	23	21
Chironomidae																					
larvae	6	59	3	8	20	3	9	10	7	12	0	0	6	0	3	19	28	10	6	52	17
pupae	2	1	3	1	5	3	1	10	3	1	0	0	1	0	0	1	0	0	1	0	16
adults	8	3	86	12	31	86	1	26	26	0	0	0	1	0	0	0	0	0	2	0	39
Simuliidae	1	3	1	1	5	0	8	8	1	19	22	1	12	24	1	12	5	2	1	8	1

Both the composition of the drift and food habits of trout changed markedly at dusk (1600–2000) and dawn (0400–0800). Collembola still dominated the drift, but were usually not consumed by either fish size. Densities of adult and pupal chironomids were much lower than daytime levels, while turbellarians (*Polycelis* sp.) and simuliids (*Twinnia nova*) exhibited relative frequency increases. As was the case during the day, trout diet was a poor reflection of drift composition. Small trout generally did not show a marked preference for any particular prey. Large trout fed chiefly on turbellarians, caddisfly larvae, and snails (*Gyraulus* sp.), plus a few chironomid adults only at dusk. Although snails and caddisfly larvae figured prominently in the food of both fish sizes, these taxa made up very low fractions of the drift during dusk and dawn.

Collembola dominated the night drift (2000–0400) to a lesser extent, with Turbellaria and Simuliidae being the other important taxa. What little night feeding there was by trout was restricted mostly to snails, turbellarians, simuliid larvae, and caddisfly larvae. Chironomid larvae, which were usually well represented in fish stomachs during daylight hours, were rarely consumed at night.

The diet of large trout tended toward greater dominance by a single type of food (chironomid adults during midday, turbellarians at dusk and dawn, snails at night) than did the diet of small trout, which as a whole tended to consume several taxa in similar quantities. Large trout had apparently become more specialized in their prey selection than had the smaller fish.

Both sizes of trout were size selective. Although small invertebrates made up the greatest percentages of the drift, they were generally ignored by the fish at all hours. This was especially true during the midday peak in drift density, when very few organisms <3 mm were taken.

All taxa that were rarely or never eaten by trout were represented in the drift by individuals <2.0 mm. Included in this group were Hydracarina, Ostracoda, Copepoda, and Collembola. Taxa that were more frequently preyed upon were represented by larger organisms that possessed a broader size distribution; included in this group were Turbellaria, Gastropoda, Ephemeroptera, Trichoptera, Chironomidae, and Simuliidae. There was also evidence that the larger members of certain taxa were being differentially cropped (Table 3). Both sizes of trout consumed significantly larger larval Chironomidae, Trichoptera, and Ephemeroptera from among those available. In addition, large trout ate significantly larger chironomid and caddisfly larvae than did small trout. These results complement recent evidence of size selectivity by *S. trutta* (Neveu and Thibault 1977) and *S. clarki* (Aho 1976) in streams.

TABLE 3. Average lengths of three groups of invertebrates in the drift and in the stomachs of small and large trout over the 28-h period. * indicates significant ($P < 0.05$) difference from drift; ** indicates significant difference from both drift and small trout as tested by analysis of variance.

Organisms	Avg length (mm) in		
	Drift	Small trout	Large trout
Ephemeroptera larvae	2	5*	5*
Trichoptera larvae	2	4*	5.5**
Chironomidae larvae	3	4*	5.5**

Discussion

Although feeding behavior was not observed directly, I inferred that some of the food ingested by large and small fish was taken from the stream bottom during certain times of the day. Species of invertebrates were occasionally found in fish stomachs that did not occur at all in the drift samples. In other instances certain sizes of various taxa, e.g. large caddisfly larvae, which

were not present in the drift, were eaten by trout. More often, however, invertebrates whose presence on the upper surface of stones made them especially conspicuous were sometimes consumed in comparatively large quantities by the fish. The most important of such taxa were *Gyraulus* sp., *Polycelis* sp., *Twinnia nova*, and *Ecclisomyia maculosa* (Trichoptera: Limnephilidae). While these taxa did occur at low levels in the drift, their occasional heavy exploitation by trout suggested that most were being foraged from the bottom.

Comparisons of the availability of different prey taxa (drift density and size distribution, conspicuousness on the bottom) with the composition and size distribution of food items in fish stomachs suggested that both sizes of trout were almost exclusively drift feeders during the midday hours of 0800–1600. At dusk there was no consistency among the preferred feeding modes. At dawn bottom foraging predominated, although a few individuals fed on both benthos and drift. During the darkness hours of 2000–0400 the fish appeared to feed exclusively off the bottom, and more trout were captured on the riffle than at other times. A few large trout did not eat anything during the 2400–0400 period. In general, drift feeding was associated with periods of highest illumination and food abundance. Bottom foraging occurred at low levels of light and drift density.

Although application of these findings to rainbow trout populations in natural streams is constrained by the experimental design (starved fish at high densities, with a relatively short time for acclimation), the results clearly indicated that both sizes of rainbow trout were selective in their food habits and that much of the selectivity was due to size differences among prey organisms. Selection, i.e. nonconsumption of small prey, was apparent at all hours and included periods when both drift feeding and bottom foraging predominated. The fish were size selective despite having been deprived of food for 2 d — an observation similarly noted in planktivorous rainbow trout by Ware (1971). I did not determine whether small prey were actively rejected by the trout or were simply not perceived as available food. Ware (1972) showed that size selectivity among rainbow trout held in laboratory aquaria was due to differences in food visibility. In this study it was also possible that the trout were unable to distinguish small invertebrates from other fine particulate material (algae and organic detritus) in the drift, or, in the case of the Collembola, from terrestrial debris floating on the surface.

Bioenergetic considerations are often given as the underlying reasons for food selectivity by foraging predators; whether or not a particular prey will be eaten depends upon the relative metabolic cost of search, pursuit, capture, and handling vs. the energy reward of capture. Salmonids in streams presumably expend relatively more energy maintaining a feeding position and relatively less energy in the active pursuit of prey than their lake-dwelling counterparts. Consequently, the advantages of size specialization to drift feeders would appear to be reduced because even small prey items might repay the cost of capture. Therefore, unless the great majority of tiny invertebrates sampled in this study were not recognized by either size of trout, it seems surprising that organisms comprising size fractions (1–2 mm) that held the bulk of the total drift density were not more fully exploited by the fish.

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Chemical and Sensory Analysis of Ungutted Offshore (Nonspawning) Capelin (*Mallotus villosus*) Stored in Ice

J. R. BOTTA, P. B. NOONAN, AND J. T. LAUDER

Department of Fisheries and the Environment, Fisheries and Marine Service, Inspection and Technology Branch, Seafood Technology Section, St. John's, Nfld. A1C 5X1

BOTTA, J. R., P. B. NOONAN, AND J. T. LAUDER. 1978. Chemical and sensory analysis of ungutted offshore (nonspawning) capelin (*Mallotus villosus*) stored in ice. J. Fish. Res. Board Can. 35: 976–980.

Based on changes in chemical and sensory variables, the keeping time of ungutted offshore capelin (*Mallotus villosus*) stored in ice was ~12 d, which was superior to other pelagic fish such as inshore (spawning) male capelin, Atlantic herring (*Clupea harengus harengus*) and Atlantic mackerel (*Scomber scombrus*). Free fatty acid, hypoxanthine, trimethylamine, and moisture content as well as iodine number and muscle pH significantly ($P \leq 0.05$) changed during 16 d of iced storage. Although changes in lipid content and peroxide value were statistically significant ($P \leq 0.05$), it is questionable whether these changes were chemically significant. Hypoxanthine and trimethylamine appeared to have the most potential for use as indices of sensory quality deterioration during iced storage.

Key words: capelin, flavor, free fatty acids (FFA), hypoxanthine, iced storage, odor, overall acceptability, peroxide value, texture, trimethylamine (TMA)

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L'analyse chimique et sensorielle démontre que la durée de conservation du capelan (*Mallotus villosus*) du large, non éviscéré et entreposé dans la glace, est d'environ 12 jours. Cette période est plus longue que celle d'autres poissons pélagiques, tels le capelan mâle (en fraie) des eaux côtières, le hareng atlantique (*Clupea harengus harengus*) et le maquereau bleu (*Scomber scombrus*). La teneur en acides gras libres, en hypoxanthine, en triméthylamine et en eau, ainsi que l'indice d'iode et le pH du muscle changent de façon significative ($P \leq 0.05$) en l'espace de 16 jours d'entreposage dans la glace. Bien que les changements dans la teneur en lipides et la valeur du peroxyde soient significatifs au point de vue statistique ($P \leq 0.05$), on doute qu'ils le soient au point de vue chimique. L'hypoxanthine et la triméthylamine sont les deux composés qui semblent les plus prometteurs comme indices de la détérioration de la qualité au cours de l'entreposage dans la glace.

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INSHORE (spawning) capelin, although suitable for human consumption, may suffer from quality defects (variable and at times very low quality) due to spawning (Jangaard 1974; Shaw and Botta 1975a, b, 1977; Templeman 1948). In addition, these fish occur when fish processing plants are busy processing the more valuable trap-caught cod.

Alternatively, offshore (nonspawning) capelin are not subject to quality defects caused by spawning and may be harvested at times more suitable for fish processing plants. Here, we report the acceptability of offshore capelin for human consumption and their quality changes during 16 d of iced storage.

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Materials and Methods

Offshore capelin were caught along the northeast coast of Newfoundland and Labrador (off St. Anthony) November 5, 1976. Immediately after capture, whole fish (mixed sex) were iced well (1 part fish to 1 part ice) and sampled after 0, 2, 4, 7, 10, 13, and 16 d storage. At each sampling period, a number of fish were gutted, beheaded, washed, and placed in 454-g capacity waxed cardboard boxes. At each sampling period, three boxes were filled for chemical analyses and two boxes for sensory analyses. All samples were frozen at −26°C. In addition, 43 boxes of ungutted capelin, sampled shortly after catching, were frozen at −26°C for subsequent use as controls for the sensory analyses. On reaching port, all samples were stored at −40°C until analyzed. The sensory samples were analyzed within 1 mo, the chemical samples within 4 mo.

An analytical panel of six judges, all trained in dif-

ferentiating appearance, texture, odor, flavor, and overall acceptability of ice-stored offshore capelin, used a five-point descriptive scale to score each sample. A score of 5 indicated the highest quality and was defined such that appearance was desirable (silver sheen to skin and white flesh); texture was moist, tender, flaky, and juicy; odor was a typical fresh capelin odor; flavor was fresh, slightly sweet, with no off-flavor; and overall acceptability was very good. A score of 1 indicated the lowest quality and was defined such that appearance was undesirable (no sheen, offcolor, mushy, partially decomposed, and oily); texture was very mushy, oily, slightly decomposed, and very moist; odor was putrid, slightly rancid, strongly ammoniacal, and very fishy; flavor was putrid, bitter, slightly rancid, and very stale; and overall acceptability was spoiled. An overall acceptability score of 2 represented unacceptability for human consumption. Each judge evaluated three samples for each storage time giving a total of 18 observations for each sensory variable per storage time. The samples were presented to the panel in a random order. To aid the judges, a control sample was presented to each judge at each panel session.

The samples were placed inside plastic bags and thawed in water at 20°C for 2 h. The fish were baked in aluminum trays, covered with aluminum foil, for 14 min at 230°C in a conventional oven and then served hot on an electric warming tray. In general, all samples were evaluated within 15 min of serving.

Hypoxantine, total lipid, free fatty acid, peroxide value, and muscle pH were determined by methods described or annotated by Shaw and Botta (1975a). Iodine number and moisture concentration were analyzed by the methods of AOAC (1975). Trimethylamine concentration was determined by the method of Tozawa et al. (1971).

Since the sensory evaluation data were small whole numbers, the data were transformed using the $(\sqrt{x + 0.5})$ transformation before conducting analyses of variance (ANOVA) (Sokal and Rohlf 1969). Analyses of variance were conducted on the transformed appearance, texture, odor, flavor, and overall acceptability data with a randomized complete block design in which all factors were considered fixed. Homogeneity of variance of the chemical variables was tested by Bartlett's test. If this test was significant, the data were appropriately transformed before conducting the ANOVA (a completely randomized design). Unless otherwise indicated, "significant" means significant at the 5% level ($P \leq 0.05$).When the storage time effect was significant, Duncan's new multiple range test was used to determine the differences among storage times. We determined correlation coefficients from the means of the variables, remembering that a correlation coefficient indicates only an association and not a cause-and-effect relationship.

Results and Discussion

Sensory Analyses

The appearance data had a significant judge–storage time interaction that precluded meaningful interpretation of these data. However, at 0 time, the mean appearance score was 4.39 ± 0.70, indicating that, in general, there was a slight loss of sheen and a very slight discoloration of the flesh. At day 16, the mean was 1.44 ± 0.51, suggesting that, as a whole, appearance was offcolored, mushy, oily, and slightly decomposed. While handling the capelin, it was observed that at day 7, very little belly burn and reddening of the flesh adjacent to the visceral cavity was present; whereas at day 13, belly burn and reddening was observed in the majority of the capelin sampled.

Table 1. Storage time means (of 18 observations) and results of Duncan's new multiple range test for texture, odor, and overall acceptability of offshore capelin stored in ice. Means are presented only where the storage effect was found significant in the ANOVA. Means not sharing the same letter are significantly different from each other.

Days of storage	Mean texture score	Mean odor score	Mean overall acceptability score
0	4.28[a]	4.22[a]	4.22[a]
2	3.94[a]	3.94[a]	3.89[a]
4	3.72[ab]	3.66[ab]	3.83[a]
7	3.22[bc]	3.16[bc]	3.11[b]
10	3.00[c]	2.83[c]	2.44[c]
13	2.11[d]	1.83[d]	1.78[d]
16	1.61[e]	1.33[e]	1.33[e]

Texture did not significantly change until day 7 and did not significantly change again until days 13 and 16 (Table 1). Texture became unacceptable after ~13 or 14 d of iced storage (Table 1). Thus, texture of iced offshore capelin became unacceptable faster than that of iced inshore male capelin (Shaw and Botta 1975a). (Unless otherwise indicated, any reference to iced inshore male capelin refers to this paper.) This is because although texture changes occurred with iced inshore male capelin, they were subjectively assessed as positive changes since they made inshore male capelin more acceptable.

Odor of offshore capelin progressively deteriorated during 16 d of iced storage until it became borderline in acceptability after ~12 or 13 d of iced storage (Table 1).

The flavor data contained a significant judge–storage time interaction which precluded meaningful interpretation of the results. However, at 0 time, the mean flavor score was 4.17 ± 0.71, indicating that in general, flavor was moderately neutral, slightly sweet, very slightly oily, with a very slight off-flavor. At day 16, the mean for flavor was 1.33 ± 0.49, suggesting that, in general, flavor was slightly ammoniacal, moderately bitter, moderately putrid, very slightly rancid, and stale.

Overall acceptability of iced offshore capelin progressively declined during 16 d of storage (Table 1). Although there was no significant change for the first 4 d, overall acceptability declined rapidly during the final 12 d of storage (Table 1). Offshore capelin stored in ice (1 part fish to 1 part ice) had a storage life of ~12 d (Table 1). These data indicated that iced offshore

TABLE 2. Storage time means (of three observations) and results of Duncan's new multiple range test for total lipid content, free fatty acid content, iodine number, and peroxide value of offshore capelin stored in ice. Means are presented only where the storage time effect was found significant in the ANOVA. Means not sharing the same letter are significantly different from each other.

Days of storage	Mean lipid content (g/100 g fish)	Mean free fatty acid content (% total lipid)	Mean iodine no.	Mean peroxide value (meq $Na_2S_2O_3$/1000 g fat)
0	12.00^{ab}	1.78^{abc}	130.0^{a}	10.02^{ab}
2	14.13^{a}	1.43^{ab}	124.9^{bcd}	8.55^{abc}
4	9.65^{b}	1.63^{abc}	129.1^{ab}	13.42^{a}
7	9.55^{b}	1.27^{a}	124.3^{cd}	7.36^{bc}
10	10.37^{b}	1.87^{bc}	127.2^{abc}	5.57^{c}
13	9.36^{b}	2.43^{d}	128.0^{ab}	12.18^{a}
16	10.41^{b}	2.06^{cd}	121.7^{d}	13.13^{a}

capelin had a superior storage life to inshore male capelin.

CHEMICAL ANALYSES

Changes associated with lipid — The total lipid content of offshore capelin significantly changed during 16 d of iced storage. However, closer analysis indicated that a peculiar value, at day 2 (which was of similar magnitude when reanalyzed), accounted for the significant difference (Table 2). It is not known why this value was of such magnitude, unless, by chance alone, the fish in this sample were substantially fatter. In general then, lipid concentration did not substantially change (Table 2) which is what one would normally expect unless there was substantial rancidity. The lipid content of 12% at 0 time was as follows: moderately lower than that of other offshore capelin caught off the coast of Labrador during November; ~3 or 4 times the lipid content of inshore capelin caught during June; slightly greater than the lipid content of autumn-spawning herring caught during November; but slightly less than the lipid content of spring-spawning herring caught during November (Eaton et al. 1975; Hodder et al. 1973; MacCallum et al. 1969).

Free fatty acid (FFA) concentration of offshore capelin stored in ice for 16 d significantly changed during that period. The concentration of FFA did not become significantly greater than that at 0 time until day 13 (Table 2). Thus, although FFA level significantly increased, the rate was very slow, much slower than that observed with iced inshore male capelin, indicating that in the present experiment hydrolysis of lipid was not very substantial. Changes in FFA content did not significantly correlate with changes in texture, odor, or overall acceptability (Table 3). This observation agreed with that of inshore male capelin stored in ice.

TABLE 3. Correlation coefficients (r) of chemical parameters versus sensory parameters for offshore capelin stored in ice ($n = 7$ in each case). *Significant at the 5% level ($P \leq 0.05$); **Significant at the 1% level ($P \leq 0.01$).

Chemical	Parameters: Texture	Odor	Overall acceptability
Total lipid	0.5360	0.5403	0.5153
Free fatty acids	−0.6650	−0.6920	−0.6862
Iodine no.	0.5646	0.5367	0.5310
Peroxide value	−0.3271	−0.3331	−0.2024
Hypoxanthine	−0.7678*	−0.7709*	−0.8100*
Trimethylamine	−0.9195**	−0.9317**	−0.9513*
Moisture	−0.9246**	−0.9144**	−0.8837**
Muscle pH	−0.8415*	−0.8380*	−0.8712*

Although iodine number significantly changed during the course of the experiment, there were no meaningful trends except the significant decrease between days 13 and 16, which may have indicated early (subthreshold) stages (if any) of rancidity (Table 2). The iodine number of 130.0 at 0 time was of a smaller magnitude than that of freshly frozen inshore male capelin (Shaw and Botta 1977). An iodine number of 130.0 represents a reasonable degree of unsaturation in the component fatty acids of the lipid. Changes in iodine number did not significantly correlate with changes in texture, odor, or overall acceptability (Table 3).

Peroxide value significantly decreased (Table 2). The mean peroxide value of greatest magnitude was 13.40 at day 4 (Table 2). The present results indicate that in all probability, substantial rancidity did not develop. With the present experiment, the increase in peroxide value was less than that observed with inshore male capelin stored in ice. During ~2 wk of iced storage, peroxide value of mackerel changed to a much greater extent than that observed with the present samples (Lemon and Regier 1977; Stansby and Lemon 1941). It is not known why the 0 time capelin sample had such a high peroxide value (Table 2). Peroxide value did not significantly correlate with changes in texture, odor, or overall acceptability (Table 3).

Miscellaneous chemical changes — Hypoxanthine concentration increased rapidly during the first 10 d of storage (Table 4). Hypoxanthine content did not increase to the same magnitude and was not nearly as variable as that reported for iced inshore male capelin, possibly reflecting differences in the physiological condition at time of catching between inshore and offshore capelin. The rate of increase in hypoxanthine level was substantially less than that observed with iced mackerel (Fraser et al. 1968). Changes in hypoxanthine concentration significantly correlated with changes in texture, odor, and overall acceptability, suggesting that this parameter may be a good indicator of quality for iced offshore capelin (Table 3).

TABLE 4. Storage time means (of three observations) and results of Duncan's new multiple range test for hypoxanthine concentration, trimethylamine concentration, moisture content, and muscle pH of offshore capelin stored in ice. Means are presented only where the storage time effect was found significant in the ANOVA. Means not sharing the same letter are significantly different from each other.

Days of storage	Mean hypoxanthine concn (mg/100 g fish)	Mean trimethylamine concn (mg TMA-N/ 100 g fish)	Mean moisture content (%)	Mean muscle pH
0	11.2[a]	0.158[a]	69.83[a]	7.12[a]
2	11.9[a]	0.164[a]	71.95[ab]	7.15[a]
4	16.5[b]	0.341[ab]	75.56[bc]	7.14[a]
7	18.5[b]	1.264[b]	77.19[cd]	7.29[b]
10	21.9[cd]	6.619[c]	75.65[bc]	7.27[b]
13	21.1[d]	10.622[d]	78.33[cd]	7.33[b]
16	18.9[bc]	9.050[cd]	80.90[d]	7.28[b]

Trimethylamine (TMA) concentration significantly increased from 0.158 mg TMA-N/100 g fish at day 0 to 10.622 at day 13 and 9.050 at day 16 (Table 4). Trimethylamine level did not significantly increase until day 7 and then rapidly increased every 3 d until day 13 (Table 4). This suggests that substantial degradation of the fish began to occur at ~ day 7 or 8. In general, during the first 8 d of iced storage of the present experiment, the rate of increase in TMA was less than that observed with iced mackerel during 8 d of iced storage (Lemon and Regier 1977). However, at day 7, the rate of increase in TMA content in our samples increased sharply and this rapid rate continued until day 13 (Table 4). Except for the nonsignificant change between days 13 and 16, the present pattern of change was similar, but less variable, to that observed with iced inshore male capelin. Changes in TMA value significantly correlated with changes in texture, odor, and overall acceptability, suggesting that TMA may be a good index of quality for iced offshore capelin (Table 3). This result differs from that observed with iced herring (Varga 1976).

Moisture content significantly increased from 69.83% at day 0 to 80.90% at day 16 (Table 4). The most rapid change in moisture occurred during the first 4 d (Table 4). The present pattern of moisture change differed from that of iced inshore male capelin in that there was no decrease during the early stages of iced storage. This may be accounted for by the lack of a rapid drop in muscle pH during these early stages of iced storage (Table 4). However, the moisture changes of inshore male capelin, after 3 d of iced storage, were similar to those of the present experiment (Table 4). With the present samples, changes in moisture level significantly correlated with changes in texture, odor, and overall acceptability (Table 3). These significant correlations were probably fortuitous occurrences.

Muscle pH significantly increased from 7.12 at day 0 to 7.28 at day 16 (Table 4). Muscle pH did not significantly change until day 7 and did not significantly change again (Table 4). Muscle pH values of the present experiment were within the range of magnitude observed with iced inshore male capelin but the pattern of change was substantially different (no rapid decrease in muscle pH during the early stages of iced storage) and the range was considerably smaller. Changes in muscle pH significantly correlated with texture, odor, and overall acceptability changes (Table 3). These results may have been fortuitous occurrences.

Conclusions

Offshore (nonspawning) capelin had a far greater lipid content and an iodine number of a smaller magnitude than those observed previously for inshore (spawning) male capelin. Curiously, the lipid components of offshore capelin were more stable than those reported previously for inshore male capelin. Such differences probably related to the physiological status of the fish as well as to differences in iodine number magnitude, although the fact that female capelin were included in the present study may have some bearing. The stability of these fish to rancidity is being further explored in our laboratory. The storage life of offshore capelin in ice was substantially better than that of inshore male capelin, herring, and mackerel (Burgess et al. 1965; Lemon and Regier 1977; Shaw and Botta 1975a; Stansby and Lemon 1941; Stroud 1972; Varga 1976). Hypoxanthine levels rose markedly prior to the rapid decline in sensory parameters, while TMA levels rose dramatically in concert with the loss in overall acceptability (Tables 1, 4). However, changes in peroxide value indicated that substantial rancidity probably did not develop (Table 2). These data indicate that deteriorative changes (chemical and microbiological) other than changes associated with rancidity were involved in the deterioration of iced offshore capelin. The results of the present study indicated that for human consumption, offshore capelin are a superior resource compared with inshore male capelin and that hypoxanthine and TMA appear to be valuable indices of loss in sensory properties.

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Larvae and Pelagic Juveniles of Blackgill Rockfish, *Sebastes melanostomus*, Taken in Midwater Trawls off Southern California and Baja California

H. GEOFFREY MOSER AND ELBERT H. AHLSTROM

National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Center, La Jolla, Calif. 92038, USA

MOSER, H. G., AND E. H. AHLSTROM. 1978. Larvae and pelagic juveniles of blackgill rockfish, *Sebastes melanostomus*, taken in midwater trawls off southern California and Baja California. J. Fish. Res. Board Can. 35: 981–996.

Examination of 217 midwater trawl samples from the coastal basins off southern California and Baja California revealed a recurring group of rockfish species. The late larvae and pelagic juveniles of the blackgill rockfish, *Sebastes melanostomus*, constituted 16% of the total number of rockfish specimens. The life-history stages of this species are described, with emphasis on the pelagic juvenile stage. Late stage larvae and pelagic juveniles develop a distinctive pattern of melanophore bands which, by disrupting the body outline, may help conceal the young during their midwater existence. Evidence from midwater trawl collections suggests that 30-mm pelagic juveniles migrate or are carried shoreward at a depth of ~200 m to the appropriate habitat for settling. The high relative abundance of blackgill rockfish pelagic juveniles in midwater trawl samples suggests that this species may represent a potential resource.

Key words: blackgill rockfish, *Sebastes melanostomus*, larvae, pelagic juveniles, midwater trawls, developmental stages, melanophore patterns, life-history strategy, head-spine development

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L'examen de 217 échantillons prélevés au chalut mésopélagique dans les bassins côtiers au large de la Basse-Californie et du sud de la Californie a permis de mettre en évidence la réapparition d'une espèce de sébaste dans cette région. Des stades larvaires avancés et des juvéniles pélagiques de *Sebastes melanostomus* constituaient 16% du nombre total de spécimens de sébastes. Nous décrivons les stades du cycle biologique de cette espèce, en mettant l'accent sur le stade juvénile pélagique distinctif. Le stade larvaire avancé et les juvéniles pélagiques se distinguent par leurs bandes de mélanophores qui, en brisant le contour du corps, peuvent contribuer à dissimuler les jeunes durant leur vie pélagique. Certaines données recueillies grâce au chalut portent à croire que les juvéniles pélagiques de 30 mm migrent vers le rivage ou y sont transportés jusqu'à une profondeur d'environ 200 m, où ils trouvent leur habitat définitif. L'abondance relative élevée des juvéniles pélagiques de *Sebastes melanostomus* dans les échantillons de chaluts mésopélagiques porte à croire que cette espèce pourrait représenter une ressource exploitable.

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IN recent years the rockfishes, now referred to the genus *Sebastes*, have become increasingly important as a commercial and recreational resource in coastal waters from Mexico to Alaska. In California, for example, rockfishes increased from 29 to 71% of the party-boat catch during the 10-y period from 1965 to 1974 (McAllister, 1976). During this same period the commercial landings of rockfishes in California more than doubled and increased fivefold in value (Greenhood and Mackett 1967; McAllister 1976). Along the entire Pacific coast commercial landings of rockfishes, excluding *Sebastes alutus*, increased from 18.8 to 28.9 million pounds (8535 to 13 120 tonnes (t)) over the same period (Verhoeven 1976).

The Pacific ocean perch (*S. alutus*) has presented a striking example of overexploitation. Until 1960, the northeastern Pacific stocks of this species were fished only by United States and Canadian trawlers, who took fewer than 5000 t annually and only fished in the southernmost portion of the range of commercially abundant stocks (southern Oregon to central British Columbia). By 1965, however, the Russians and Japanese, who had entered the fishery in 1960 off

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Alaska, had expanded their fishery southward to southern Oregon. In 1965 their total catch peaked at 520 000 t (Chikuni 1975). Thereafter the fishery declined rapidly and stabilized at about one-fourth that of the peak catch. The overexploitation of *S. alutus* demonstrates the need for effective management of other rockfish species, which are subjected to increased fishing pressure. The problem is complicated by the large species complement (about 70), difficulties in identification, and inadequate knowledge of the life histories of many species.

Sampling the planktonic larvae of *Sebastes* is one of the potential means of estimating year-class abundance at an early age; however, the early developmental stages are known for only a few species (Moser et al. 1977). At the end of the larval period the species of *Sebastes* follow divergent strategies. Some, like *S. paucispinis*, move to inshore nursery areas such as eelgrass beds (Moser 1967). Others, like *S. diploproa* and *S. rubrivinctus*, spend their early juvenile life in masses of floating kelp and flotsam (Mitchell and Hunter 1970; Boehlert 1977). Still others, such as *S. macdonaldi*, have an extended pelagic juvenile stage (Moser 1972).

A study of the *Sebastes* larvae and juveniles taken by midwater trawl in the deep-water basins off southern California and Baja California revealed a recurring group of a few common types. One of these, the blackgill rockfish (*S. melanostomus*), has a striking pigment pattern and could be assembled into a continuous developmental series from 6.2 to 46.2 mm. In this paper we describe this series and point out the potential of using the pelagic juvenile stages of certain species of *Sebastes* in resource assessment.

Materials and Methods

A total of 217 midwater trawl collections containing *Sebastes* larvae and juveniles was examined; of these, 202 were provided by the Los Angeles County Museum of Natural History, 6 by the Scripps Institution of Oceanography (SIO) Fish Collection, and 9 by the National Marine Fisheries Service, La Jolla. Of the Los Angeles County Museum collections all but 20 were made with an open 10-ft (3-m) Isaacs-Kid midwater trawl. Two were made with an open 30-ft (9-m) midwater trawl, 1 was made with a 6-ft (1.8-m) ring net, and 17 were discrete depth samples made with an acoustically operated 6-ft (1.8-m) Tucker opening–closing net. The open midwater trawls were fished horizontally at maximum depth for 2 h. Maximum depths ranged from 10 to 1350 m (Table 1) over a range of bottom depths of 210–4389 m ($\bar{x} = 2225 \pm 973$ SD). Depths sampled by the opening-and-closing nets are listed in Table 1.

A total of 1310 larvae and juveniles of *Sebastes* was examined of which 211 (16%) represented *S. melanostomus* (Table 2). The distribution and size frequency of *S. melanostomus* are shown in Fig. 1 and 2. Newborn larvae obtained from a pregnant female of this species, caught on March 13, 1975 and identified with the characters of Barsukov (1968), Tsuyuki and Westrheim (1970), and Miller and Lea (1972), were raised to the point of yolk depletion. These larvae helped confirm the identification of the trawl-caught series and were used in the description of the larvae. The descriptive methods follow those of Moser et al. (1977). Terminology of the head spines follows that of Eschmeyer (1969), Moser (1972), and Poss (1974).

The terminology of specimen length requires special explanation. Standard length is defined as the distance between the tip of the snout and the posterior edge of the hypural plate. In larvae that have not completed notochord flexion, and therefore do not have the posterior edge of the hypural plate in a vertical position, we measure the body length from the tip of snout to the tip of the notochord. Notochord flexion in *S. melanostomus* is completed at a length of 7.5 mm and specimen length in larvae larger than this is referred to as standard length.

Fresh specimens for aging were obtained from the stomach contents of albacore (*Thunnus alalunga*) taken in August 1977 about 80 miles (129 km) south–southwest of San Diego, Calif. The otoliths were prepared and analyzed according to the methods of Brothers et al. (1976).

TABLE 1. Maximum depths (m) of midwater trawls used in this study (Los Angeles County Museum material).

Open trawls				Discrete depth trawls	
Depth range	No. of tows	Depth range	No. of tows	Depth	No. of tows
0–50	25	601–650	5	200	6
51–100	31	651–700	11	225	1
101–150	7	701–750	1	250	1
151–200	4	751–800	3	300	1
201–250	8	851–900	7	350	3
251–300	5	901–950	6	450	1
301–350	25	951–1000	1	525	1
351–400	4	1051–1100	4	550	1
401–450	7	1151–1200	6	650	1
451–500	6	1251–1300	10	800	1
501–550	3	1301–1350	1		
551–600	4	Unknown	1		

TABLE 2. Composition of *Sebastes* identified in midwater trawl samples from southern and Baja California.

Sebastes type	No. of specimens	% total
S. aurora	16	1
S. diploproa (juveniles)	25	2
S. levis	2	<1
S. macdonaldi	4	<1
S. melanostomus	211	16
S. paucispinis	6	<1
S. rubrivinctus	51	4
Subgenus *Sebastomus*	585	45
S. spp.	410	31
Total	1310	

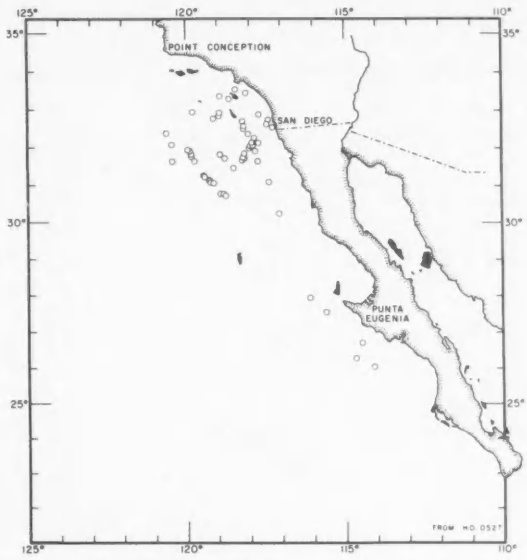


FIG. 1. Distribution of midwater trawl samples containing larvae and pelagic juveniles of *Sebastes melanostomus*.

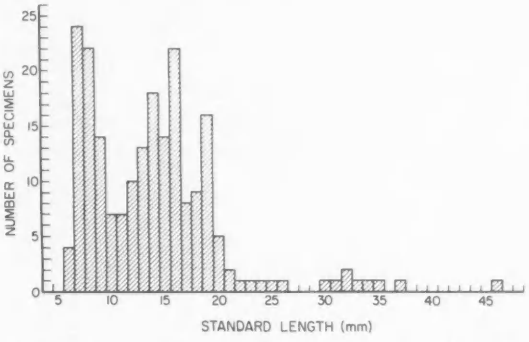


FIG. 2. Length frequency of total midwater trawl catches of *S. melanostomus* taken off southern and Baja California.

Results and Discussion

DISTINGUISHING FEATURES

Larvae of *S. melanostomus* are extruded at a length of about 4.5 mm. Although there is a gap in our series between 4.5 and 6.2 mm (Table 3), some of the pigment present on the smallest trawl-caught specimens is also evident on newborn larvae. Newborn larvae have a single row of melanophores (mean of 8 melanophores for 27 specimens counted) on the ventral midline of the tail, a patch above the brain, a heavy blotch at the tip of the lower jaw, a streak along the posterior region of the upper jaw, a pattern of minute melanophores on the pectoral fins, and a group along the dorsal and lateral surfaces of the gut (Fig. 3). A large blotch that appears on the opercle at about the completion of notochord flexion, along with the upper jaw streak that has moved anteriad, helps to distinguish larvae of this size. Older larvae and pelagic juveniles develop a striking banding, which is retained in benthic juveniles and even to some extent in adults (Fig. 3–5). Larvae and pelagic juveniles develop unusually prominent head spination. The beginning of the pelagic juvenile stage is marked by the appearance of anterior lateral-line scales in 16.0-mm specimens. The largest pelagic juvenile examined measures 46.2 mm, and the smallest demersal juvenile 36.0 mm.

MORPHOLOGY

Body proportions for larvae and pelagic juveniles of *S. melanostomus* and of four other species of *Sebastes* studied previously (Moser et al. 1977) are listed in Table 4. Larvae and pelagic juveniles of *S. melanostomus* are comparatively deep-bodied, big-headed, and have eyes of moderate size. Relative head length is considerably greater in flexion-stage larvae of *S. melanostomus* than in the other species.

The development of prominent head spines is the outstanding morphological feature of *S. melanostomus* larvae. The sequence of development of head spines in early larvae of *Sebastes* has been described for *S. macdonaldi* (Moser 1972). The more complete series of late-stage larvae and pelagic juveniles of *S. melanostomus* provides an opportunity to describe the development of these spines in greater detail. Their development and eventual fate is described in relation to the bones that bear them in the approximate sequence of their appearance (Table 5, Fig. 6 and 7).

Parietal — Parietal bones bear serrated ridges that terminate in prominent spines. Posterior to each parietal spine is a nuchal spine. Initially the nuchals are small and subjacent to the parietals; however, during larval development the nuchals enlarge in relation to the parietals and eventually equal them in size (Fig. 7B). Both spines are retained in adults.

Frontal — The frontal bone, which forms a shelf above the eye, eventually bears two spines. Initially the postocular spine forms directly above the eye but gradually moves posteriad with development to assume a rearward position above the orbit at the end of pelagic life. The second spine to develop on the shelf is the supraocular. Initially it is located forward but moves posteriad with development to a position above the center of the orbit. Supraocular and postocular spines are retained in adults. At the beginning of the pelagic juvenile stage the tympanic spine begins to form on the upper rim of a sensory-canal opening. The spine enlarges to eventually obscure the opening at the end of pelagic life. On the largest stained pelagic juvenile examined a single coronal spine is present on the right side

TABLE 3. Measurements (mm) of larvae of *Sebastes melanostomus*. Specimens between dashed lines are undergoing notochord flexion and those between solid lines are pelagic juveniles.

Specimen length	Snout–anus distance	Head length	Snout length	Eye diam	Body depth	Pectoral fin length	Pectoral fin base depth	Pelvic fin length	Snout–anal fin interval
4.5	1.7	0.96	0.28	0.36×0.39	1.0	0.25	0.23		
6.2	3.7	3.0	1.0	0.92×0.96	2.2	1.2	0.79	0.64	4.0
6.8	3.8	3.4	1.0	1.0×1.1	2.4	1.3	0.80	0.77	4.2
7.2	3.8	3.2	1.0	1.0×1.1	2.5	1.3	0.84	—	4.3
7.6	4.4	3.4	1.2	1.1×1.1	2.9	1.8	0.87	1.1	4.8
7.8	4.7	3.4	1.2	1.1×1.1	3.0	1.6	0.90	1.0	4.9
8.2	4.5	3.2	1.0	1.2×1.2	3.4	1.6	1.0	1.2	5.1
8.5	4.8	3.7	1.2	1.2×1.2	3.2	1.9	1.0	1.3	5.2
9.0	5.2	3.8	1.2	1.2×1.2	3.4	1.9	1.2	1.3	5.4
10.1	5.8	4.0	1.2	1.4×1.4	4.2	2.2	1.2	1.5	6.1
11.3	6.7	4.7	1.4	1.6×1.6	4.4	2.6	1.2	1.8	6.8
12.3	7.6	5.0	1.6	1.7×1.7	4.5	2.6	1.3	2.0	8.2
13.5	8.0	5.2	1.6	1.8×1.8	5.2	2.9	1.3	2.2	8.6
14.5	9.1	5.7	1.9	1.9×1.9	5.6	3.1	1.4	2.4	9.8
15.7	9.7	6.2	1.8	2.0×1.9	5.9	3.6	1.6	3.1	10.1
16.2	9.8	6.5	2.2	2.1×2.0	6.2	3.5	1.5	3.1	10.3
17.4	10.6	6.2	1.9	2.2×2.2	6.5	5.0	1.7	3.3	11.0
18.6	11.5	7.2	2.3	2.3×2.2	6.7	4.4	1.8	3.5	12.3
19.8	12.7	7.9	2.7	2.3×2.3	7.2	4.7	1.8	3.8	13.4
20.7	13.0	8.0	2.7	2.4×2.4	8.0	5.2	2.1	4.2	13.5
21.4	13.2	7.8	2.2	2.5×2.5	8.5	5.7	2.2	4.0	13.7
23.3	14.5	8.6	2.4	2.7×2.7	8.7	6.2	2.3	4.8	15.4
24.0	16.6	10.1	2.8	2.8×2.8	9.0	6.2	2.3	—	16.9
25.2	16.7	10.1	—	3.0×3.0	9.2	6.2	2.3	4.9	17.2
26.4	16.9	10.0	2.9	2.9×2.9	9.9	6.9	2.7	5.2	17.7
30.1	19.6	12.0	3.2	3.3×3.3	10.3	8.1	2.7	6.0	19.5
32.7	20.7	12.7	3.3	3.2×3.2	12.0	8.8	3.0	6.7	21.7
33.5	23.3	13.2	3.3	4.2×4.2	12.7	9.1	3.3	7.1	24.4
34.5	21.6	13.2	3.6	3.8×3.8	11.8	9.3	3.3	6.9	22.7
37.2	24.3	14.0	3.5	4.1×4.1	12.5	10.1	3.3	7.0	25.5
46.2	29.5	15.7	4.2	4.7×4.7	17.2	13.0	4.4	9.5	31.1
36.0[a]	22.5	12.8	2.7	4.0×4.0	13.7	10.1	3.4	7.5	24.7
42.1[a]	27.2	15.7	4.8	4.3×4.3	14.7	11.3	3.8	8.8	29.0
60.6[a]	37.9	22.0	5.2	7.5×7.5	21.4	16.9	5.8	11.8	41.1

[a]Benthic juvenile.

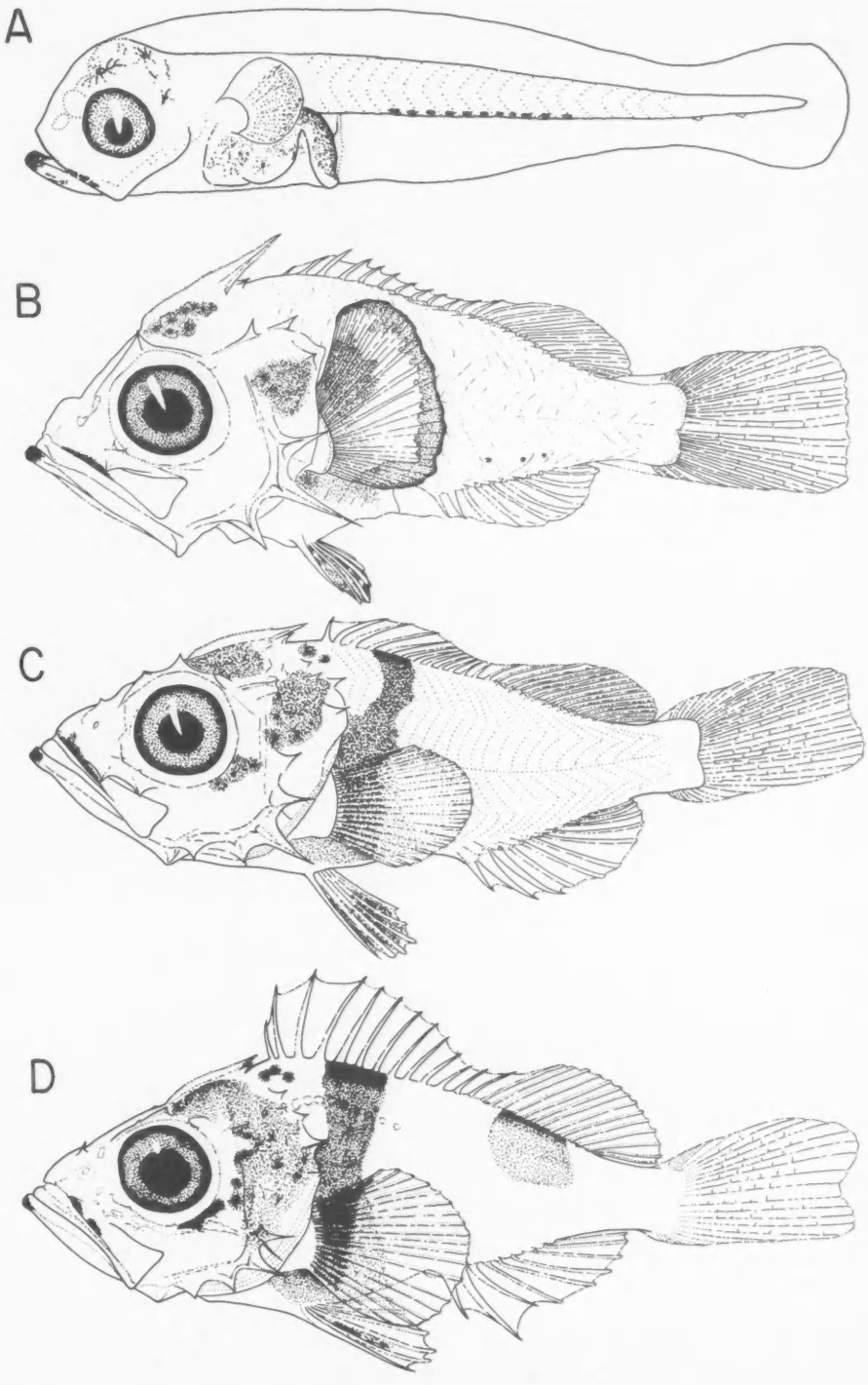
of the interorbital region. They are present on no other pelagic juveniles in our collection and are only occasionally reported in adults.

Pterotic — The large spine on the pterotic bone forms early in the larval period and remains prominent until it disappears at the end of pelagic life.

Preopercle — The spines on the preopercle form early and become highly conspicuous. Two series are formed: a posterior series of large backward-projecting spines and an anterior series of small laterally projecting spines. In the smallest stained larva the 2nd, 3rd, and 4th spines of the posterior series have already developed, and each bears in the anterior series a small spine projecting outward from its base. The 3rd posterior spine is the largest in the series and remains so until the end of the pelagic phase. The 3rd and 4th posterior spines are both serrated. The 1st and 5th posterior spines begin to form in the 6.8-mm larva and with continued enlargement during larval development become equal in size to the others. All five spines in the posterior preopercular series are retained in adults.

The spines in the anterior series do not persist. The

FIG. 3. Developmental series of *S. melanostomus*. A, 4.4-mm larva reared from pregnant female; B, 8.2-mm larva; C, 12.3-mm larva; D, 17.4-mm pelagic juvenile.


A
B
C
D

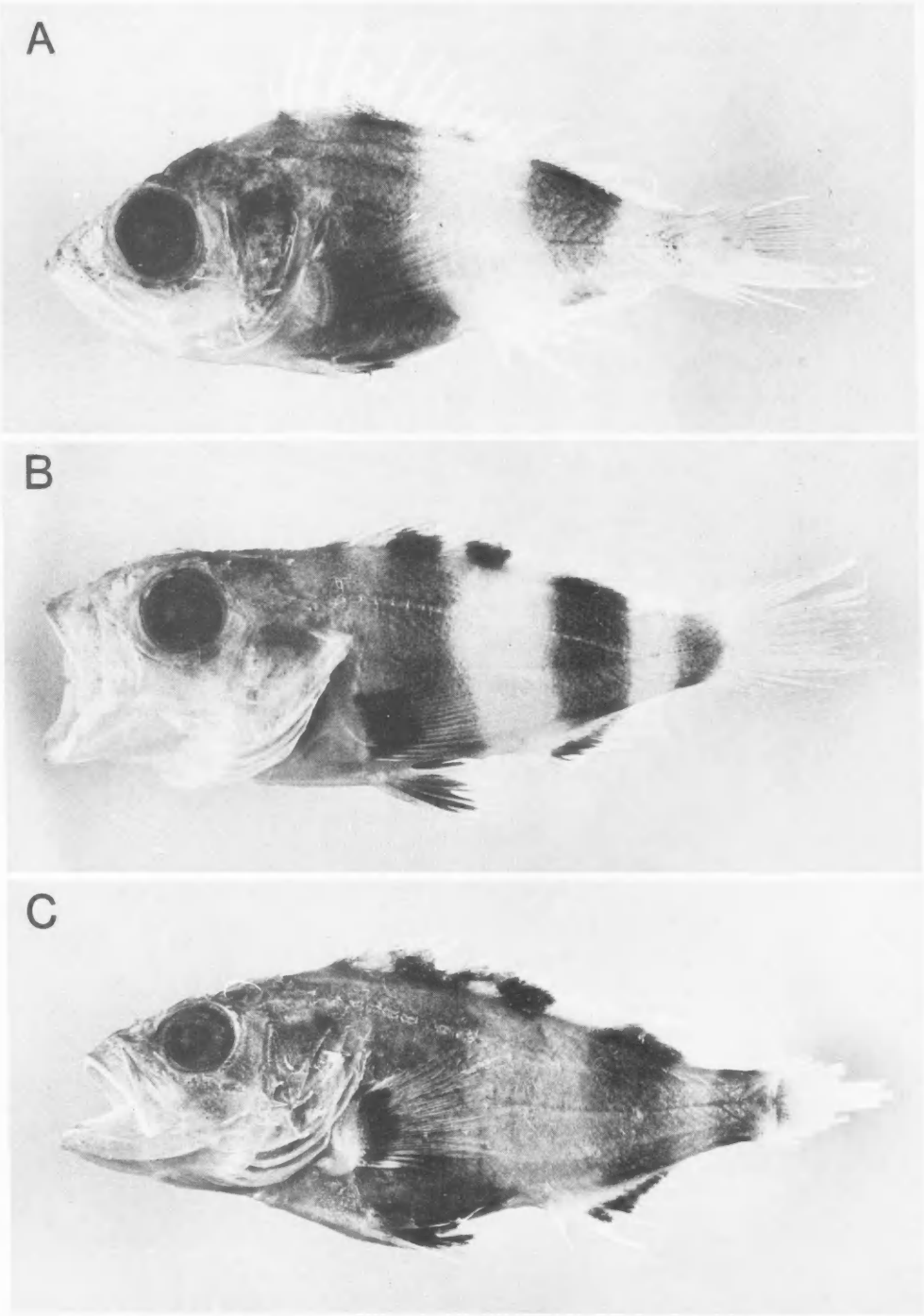


FIG. 4. Pelagic juveniles of *S. melanostomus*. A, 26.4 mm; B, 31.5 mm; C, 46.2 mm.

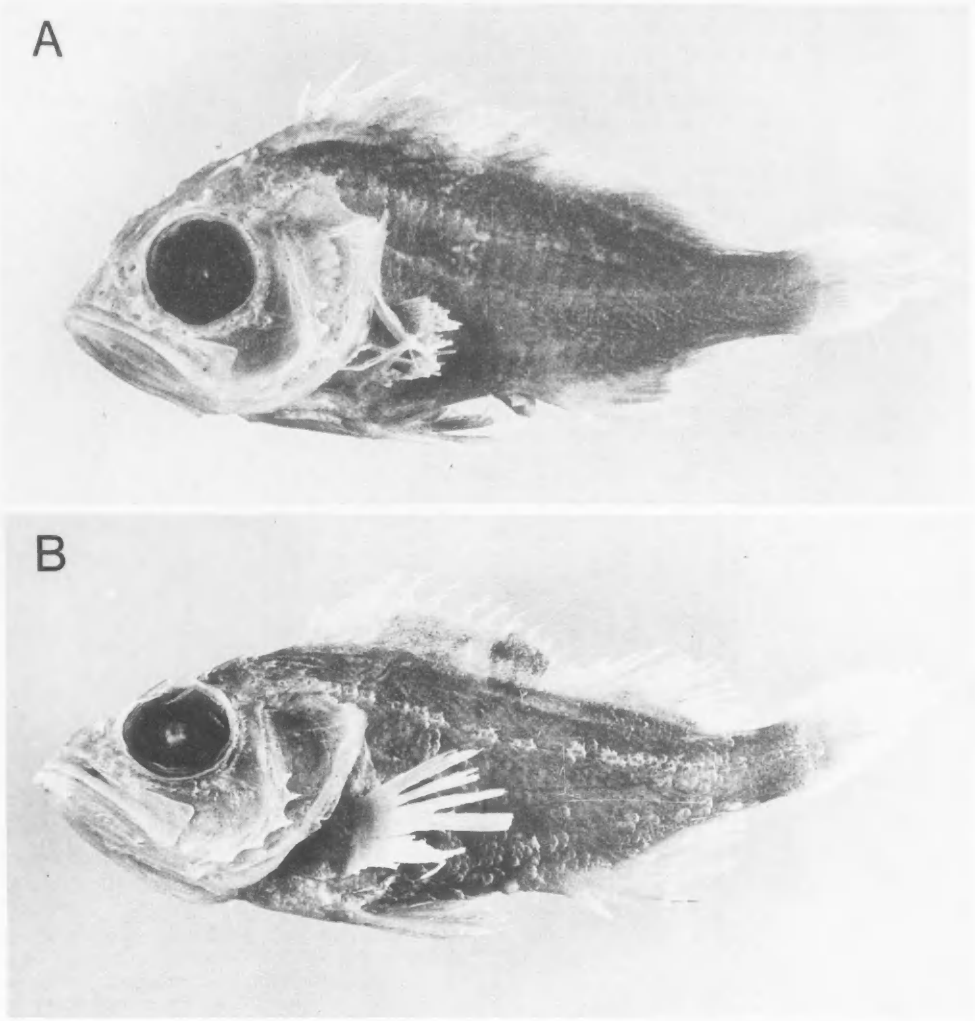


FIG. 5. Benthic juveniles of *S. melanostomus*. A, 36.0 mm; B, 42.1 mm.

one at the base of the 3rd spine of the posterior series is weakly developed or variously lacking on one or both sides until 13.5 mm, after which it is never evident. The ones at the bases of the 2nd and 4th posterior spines gradually diminish in size and are absent in individuals larger than 20.3 mm.

Opercle — A prominent spine is present on the upper posterior edge of the opercle in the smallest stained larva. This upper opercular spine has a long rod-like support that slants ventroposteriad from its point. A second opercular spine with a weaker and shorter supporting rod develops ventral to the former at about 8.8 mm. Upper and lower opercular spines are retained in adults.

Infraorbitals — Confusion and inconsistency mark the nomenclature of the series of bones that underlie the orbit of scorpaeniform fishes. Poss (1974) reviewed the historical aspects of this problem and suggested a rational terminology that we adopt here. The most anterior bone in the series, usually called the lacrymal bone by recent workers, is referred to as infraorbital 1. The next bone posterior to it, usually referred to as suborbital 1, is here termed infraorbital 2. Posterior to it the bone that bears the projection extending to the

TABLE 4. Comparative morphometry of five species of *Sebastes* (A = larvae undergoing notochord flexion, B = postflexion larvae, C = pelagic juveniles). Values given for each body proportion expressed as percentage of body length or head length: mean, standard deviation, and range.

	Snout–anus distance	Head length	Snout length	Eye diam	Body depth	Pectoral fin length	Pectoral fin base depth	Pelvic fin length
	Body length	Body length	Head length	Head length	Body length	Body length	Body length	Body length
S. jordani								
A	42.4±1.67 (41–45)	28.4±2.19 (26–30)	35.5±1.29 (34–37)	32.2±2.50 (29–35)	21.0±1.00 (20–22)	8.4±1.14 (7–10)	7.8±0.45 (7–8)	1.4±0.55 (1–2)
B	51.0±2.86 (46–54)	32.3±1.44 (31–36)	34.4±1.98 (31–39)	29.3±2.10 (27–34)	23.8±1.19 (22–26)	16.8±3.25 (11–20)	7.9±1.0 (7–10)	9.0±3.62 (3–13)
C	53.3±1.03 (52–55)	31.2±1.94 (28–33)	34.0±2.83 (30–38)	26.5±1.52 (24–28)	22.2±0.84 (21–23)	20.5±1.05 (19–22)	7.0±0.00 (7)	13.5±1.22 (12–15)
S. levis								
A	48.9±3.44 (45–56)	30.5±1.85 (28–33)	34.8±0.89 (34–36)	32.5±1.77 (30–35)	28.5±3.51 (24–35)	34.9±6.96 (24–46)	12.9±0.64 (12–14)	6.1±3.27 (2–12)
B	59.2±2.87 (57–63)	35.0±2.00 (34–38)	30.2±2.22 (28–33)	30.5±1.73 (28–32)	34.0±1.41 (33–36)	45.0±3.74 (41–50)	11.2±0.96 (10–12)	21.0±4.76 (16–26)
C	63.0±0.82 (62–64)	33.8±0.96 (33–35)	30.5±2.38 (28–33)	27.0±3.37 (25–32)	35.0±1.41 (34–37)	40.8±7.09 (32–47)	10.2±0.96 (9–11)	24.2±2.87 (22–28)
S. macdonaldi								
A	51.8±3.56 (48–56)	35.6±1.52 (34–38)	34.0±4.00 (30–38)	32.0±1.41 (31–34)	31.6±2.07 (30–35)	13.0±1.22 (12–15)	—	5.8±2.39 (3–9)
B	60.3±3.06 (55–64)	37.5±1.84 (34–41)	32.9±3.00 (29–37)	33.0±1.33 (31–35)	34.4±1.17 (33–36)	19.3±3.65 (15–26)	—	14.3±3.77 (10–21)
C	64.2±2.44 (61–68)	35.11±2.37 (32–38)	27.9±2.09 (25–32)	30.7±2.74 (26–34)	31.4±1.59 (30–34)	30.4±1.74 (28–34)	—	21.9±1.36 (21–25)
S. melanostomus								
A	56.6±2.99 (53–60)	46.8±2.75 (44–50)	32.0±2.58 (29–35)	32.5±1.00 (32–34)	35.8±1.50 (35–38)	20.0±2.71 (18–24)	12.0±0.82 (11–13)	11.7±2.08 (10–14)
B	59.1±2.69 (55–63)	40.9±2.02 (39–44)	31.5±1.72 (29–35)	33.6±2.07 (31–38)	38.9±1.52 (37–42)	21.5±0.97 (20–23)	11.3±1.06 (10–13)	15.7±1.89 (13–20)
C	63.9±2.67 (60–70)	38.4±1.97 (36–42)	29.0±3.21 (25–34)	30.1±2.29 (25–35)	36.9±1.75 (34–40)	26.1±1.75 (22–29)	9.6±0.50 (9–10)	19.7±0.80 (19–21)
S. paucispinis								
A	44.8±3.70 (40–49)	29.6±1.95 (27–32)	30.6±1.82 (29–33)	30.2±1.64 (29–33)	23.0±1.41 (21–24)	27.2±2.49 (25–31)	9.0±0.71 (8–10)	13.6±9.29 (9–26)
B	57.3±3.82 (51–61)	37.1±1.07 (36–39)	32.2±0.98 (31–33)	31.3±1.70 (28–33)	29.6±0.98 (28–31)	35.7±1.25 (34–37)	7.6±0.53 (7–8)	35.1±2.79 (31–39)
C	62.3±2.73 (60–66)	36.2±1.72 (33–38)	30.5±2.95 (26–33)	27.8±1.72 (26–30)	27.3±0.52 (27–28)	28.2±3.4 (25–34)	6.0±0.89 (5–7)	25.2±2.71 (22–30)

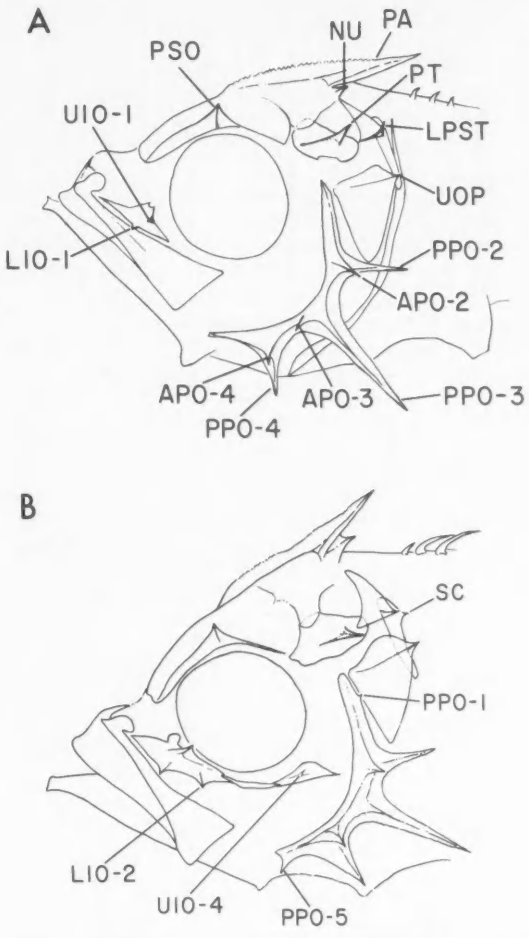


FIG. 6. Head spines in 6.2 mm (A) and 8.2 mm (B) stained larvae of *S. melanostomus*. Abbreviations of head spines: APO-2, 2nd anterior preopercular; APO-3, 3rd anterior preopercular; APO-4, 4th anterior preopercular; CL, cleithral; IOP, interopercular; LIO-1, 1st lower infraorbital; LIO-2, 2nd lower infraorbital; LOP, lower opercular; LPST, lower posttemporal; NA, nasal; NU, nuchal; PA, parietal; PPO-1, 1st posterior preopercular; PPO-2, 2nd posterior preopercular; PPO-3, 3rd posterior preopercular; PPO-4, 4th posterior preopercular; PPO-5, 5th posterior preopercular; PRO, preocular; PSO, postocular; PT, pterotic; SC, supracleithral; SPO, supraocular; TM, tympanic; UIO-1, 1st upper infraorbital; UIO-2, 2nd upper infraorbital; UIO-3, 3rd upper infraorbital; UIO-4, 4th upper infraorbital; UOP, upper opercular; UPST, upper posttemporal.

preopercle and has usually been referred to as suborbital 2 is termed the infraorbital 3.

All three bones develop spines in larvae of *Sebastes*. In our smallest stained larva of *S. melanostomus*, infraorbital 1 bears an outward-projecting spine on its upper edge and a downward-projecting one on its ventral edge. At 8.2 mm a second spine appears posteriorly on the ventral edge of the bone, and at 9.0 mm a second outward-projecting spine forms posterior to the one on the upper edge of the bone. The two upper spines develop as projections on a serrated shelf below the orbit. They become progressively reduced during pelagic life and are obsolete in benthic juveniles and adults. The two lower spines progressively enlarge with development, becoming prominent in juveniles and adults. A single outward-projecting spine develops on the upper lateral face of infraorbital 3 at 7.2 mm. As development proceeds the spine projects from a serrated shelf that rims the orbit. The spine is reduced toward the end of pelagic life and is lost in benthic juveniles. The last spine to appear in the infraorbital series projects outward from the upper edge of infraorbital 2. With development it becomes a projection of the serrated shelf below the orbit, but remains inconspicuous and disappears at the end of the pelagic period.

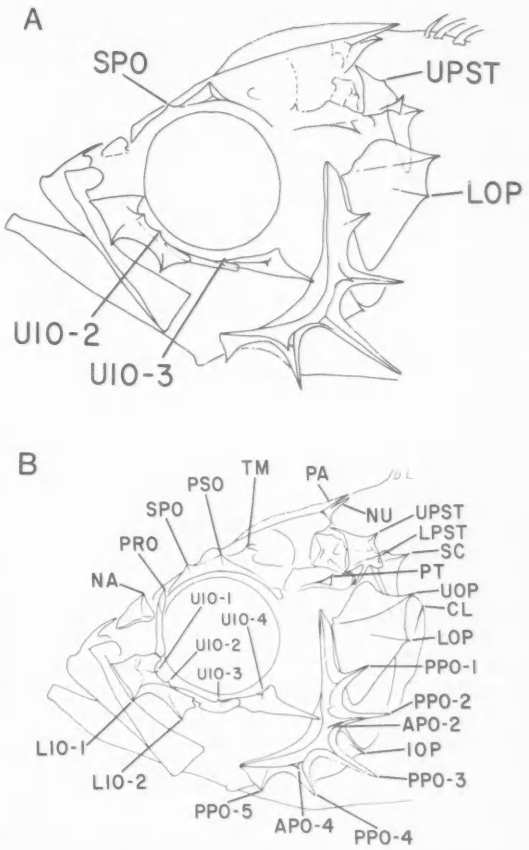


FIG. 7. Head spines in 10.0 mm (A) and 16.0 mm (B) stained larvae of *S. melanostomus*. Abbreviations as in Fig. 6.

TABLE 5. Sequence of development of head spines of *S. melanostomus*. Presence of spine is indicated by an "X" or continuous line. Absence of a spine is indicated by an "O". In asymmetrical specimens the condition on the left and right sides is separated by a slash.

Spine	Length of specimen (mm)																																
	6.2	6.8	7.2	7.5	7.7	8.2	8.8	9.0	9.4	10.0	10.6	11.8	12.0	12.8	13.2	13.5	13.8	14.2	14.7	15.2	15.7	16.0	16.9	17.1	17.7	18.4	18.9	19.5	20.3	21.1	22.4	26.9	32.2
Parietal	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nuchal	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Postocular	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pterotic	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lower post-temporal	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Upper opercular	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1st upper infraorbital	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	O	—
1st lower infraorbital	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2nd anterior preopercular	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X/O	X	X	O	O	O	O
2nd posterior preopercular	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3rd anterior preopercular	X/O	X	O	O/X	X/O	O	O	O	O	O/X	O	O	O	X	O/X	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
3rd posterior preopercular	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4th anterior preopercular	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	O	O	O	O
4th posterior preopercular	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1st posterior preopercular		X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5th posterior preopercular		X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4th upper infraorbital			X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Supracleithral				X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2nd lower infraorbital					X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lower opercular						X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2nd upper infraorbital							X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	O	—
Upper post-temporal								X	—	X	O	O	X	O/X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Supraocular										X	O	O	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3rd upper infraorbital										X	O	O	O/X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	O/X	X	—	—
Nasal													X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Preocular															X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cleithral																			X	O	O	X	—	—	—	—	—	—	—	—	—	—	—	—
Interopercular																					X	—	—	—	—	—	—	—	—	—	—	—	—	—
Tympanic																						X	—	—	—	—	—	—	—	—	—	—	—	—
Subopercular																								X	O	O	O/X	O	O	O/X	O/X	X/O	X	—
Coronal																																	O/X	—

Lateral ethmoid — The lateral ethmoid bone begins to form at the anterior rim of the orbit early in the larval period. Late in the larval period (13.2 mm) the preorbital spine begins to form as a dorsal projection from the bone. Inconspicuous at first, it enlarges to become a prominent spine in juveniles and adults.

Nasal — The nasal spine begins to form at about 12.8 mm as a dorsal projection of the nasal bone. It becomes pronounced with further development and is a prominent spine in juveniles and adults.

Posttemporal — The posttemporal bone forms two spines. In the smallest stained larva a strong spine projects outward from the ventral margin of the bone. It remains conspicuous throughout the larval period but as the lower region of the bone begins to curve inward in pelagic juveniles the spine recedes, becomes barely discernible in early benthic juveniles, and then disappears. A second spine begins to form above the lower spine on the posterior edge of the bone at 10.0 mm. In contrast to the lower posttemporal spine, the upper spine becomes progressively larger with development. It projects dorsoposteriad from the bone and is retained in juveniles and adults.

Supracleithrum — A backward-projecting spine appears on the posterior edge of the supracleithrum at 8.2 mm. It enlarges progressively with development to equal the upper posttemporal spine in size and is retained in adults.

Cleithrum — A small spine appears on the upper posterior margin of the cleithrum at 14.7 mm. It remains throughout the pelagic period, is retained in small benthic juveniles, and then lost.

Interopercular — Late in the larval period a supporting rod begins to develop at the upper margin of the interopercular, where the bone faces the subopercular. At 15.7 mm this rod projects backward as a spine which is retained throughout the remainder of the stained series. It is variously present or absent in benthic juveniles and adults.

Subopercular — In some pelagic juveniles a spine projects from the lower margin of the subopercular, where the bone faces the interopercular. In the largest stained specimen (32.2 mm) a second spine is present just above the one at the lower margin. Like the interopercular spine, these spines are variously present or obsolete in benthic juveniles and adults.

A notable feature of head-spine development in *Sebastes* is the gradual ontogenetic appearance of most of the major spines found in other scorpaenid genera. Of the 22 spines that Eschmeyer (1969) has listed for the Scorpaenidae, 19 occur in the larvae and pelagic juveniles of *Sebastes*. In genera of the subfamily Scorpaeninae, the spines that develop in larvae and pelagic juveniles are retained and typically become more prominent in adults. In *Sebastes* (subfamily Sebastinae) a number of spines gradually become reduced toward the end of the pelagic juvenile stage and are lost soon after the fish settle. Among the spines that degenerate are the infraorbitals (which are, however, retained in *S. aleutianus*, *S. macdonaldi*, and *S. phillipsi*), the anterior preoperculars, the lower posttemporals, and the pterotics. Apart from the ontogenetic appearance and loss of these spines, other spines of the complement known for *Sebastes* are lost or reduced in adults of some species (Phillips 1957). Generally spine reduction and loss is more pronounced in species that have a convex interorbital region and a streamlined head, and usually do not live directly on the bottom. This trend culminates in semipelagic species such as *S. goodei*, *S. jordani*, and *S. paucispinis*, which have little or no spination atop the head. Interestingly, spination appears to be adaptive at one life-history stage and nonadaptive at another; i.e. sebastine larvae and pelagic juveniles develop almost the complete ancestral complement of head spines, probably as an adaptation for flotation and defense. As adults, the evolutionary direction of sebastines is toward a pelagic existence that contrasts with the sedentary mode of existence of most scorpaenines and, for this, the reduction and loss of head spines is adaptive in adults and is reflected in the loss of spines during ontogeny. In concert with this, the connection between the preopercle and infraorbital 3 is reduced to allow the flexibility and streamlining that would appear to be adaptive for semipelagic life. In scorpaenines, infraorbital 3 is a broad bone that fuses with the preopercle, whereas in *Sebastes*, infraorbital 3 is T-shaped and sends a narrow projection to the preopercle but does not fuse with it.

Fin Development

In comparison with other *Sebastes* species, the pectoral fins of *S. melanostomus* are of moderate length. They increase in relative length during development (Table 3). The pectoral fin base is relatively deep as in *S. levis*. The smallest stained specimen has 17 pectoral rays, which falls within the adult complement of 17–20 (Table 6). For the remainder of the series the modal count is 19.

The pelvic fin is also of moderate length in comparison with other species and further enlarges during development (Table 3). The adult complement of 1 spinous and 5 soft pelvic rays is evident in the smallest stained specimen. In this specimen, 3 of the anterior spinous dorsal rays and 7 of the soft rays are forming. The full complement of 13–14 spinous rays is achieved in all larvae longer than 8.2 mm. Although the 13th spinous ray cannot be differentiated anatomically from the 1st soft-ray until the middle of the larval period, it is distinguished by its relative height. The most posterior

TABLE 6. Meristics from cleared and stained larvae of *S. melanostomus*.

Length (mm)	Procurrent caudal fin rays		Pectoral fin rays		Gill rakers (right arch)		Anal fin rays	Dorsal fin rays	Vertebrae
	Superior	Inferior	Left	Right	Upper limb	Lower limb			
6.2 NL	2	2	17	17	2	15	0,5	III,7	23[a]
6.8	2	—	19	19	3	15	III,7	XIII,12	26
7.2	2	3	19	19	2	15	II,7	XII,11	24[a]
7.5 SL	3	3	19	19	3	16	III,7	XIII,12	26
7.7	3	4	20	20	3	15	III,7	XIII,11	26
8.2	4	5	17	17	4	17	III,7	XIII,13	26
8.8	5	6	18	18	6	16	III,7	XIII,13	26
9.0	5	6	19	19	6	17	III,7	XIII,13	26
9.4	5	6	18	19	5	17	III,7	XIII,13	26
10.0	7	8	19	19	7	20	III,7	XIII,13	26
10.6	7	7	19	19	7	18	III,7	XIII,14	26
11.8	8	8	19	19	8	20	III,7	XIII,14	26
12.0	8	9	20	20	8	19	III,7	XIII,13	26
12.8	8	8	19	19	8	21	III,7	XIII,13	26
13.2	9	9	19	19	8	20	III,7	XIII,13	26
13.5	9	9	19	19	8	21	III,7	XIII,13	26
13.8	9	9	19	19	8	19	III,7	XIII,14	26
14.2	9	9	20	20	8	21	III,6	XIV,14	26
14.7	9	10	19	19	8	20	III,7	XIII,13	26
15.7	9	10	19	19	8	21	III,7	XIII,13	26
16.0	9	9	19	19	8	21	III,7	XIII,14	26
16.9	9	9	19	19	7	20	III,7	XIII,14	26
17.7	10	10	19	19	8	21	III,7	XIII,13	26
18.4	10	11	19	19	8	21	III,7	XIII,13	26
18.9	9	10	19	19	8	21	III,6	XIII,13	26
19.5	9	10	19	18	9	22	III,7	XIII,14	26
20.3	9	10	19	19	8	21	III,7	XIII,14	26
21.1	10	10	19	19	8	21	III,7	XIII,14	26
22.4	9	9	19	19	9	22	III,7	XIII,13	26
26.9	—	—	19	19	9	22	III,7	XIII,13	26
32.2	—	—	20	19	8	21	III,7	XIII,13	26

[a]Incomplete vertebral count.

rays are the last to appear, and the ultimate ray is distinguishable by its bifid condition.

The smallest stained specimen has no spinous anal rays, but all specimens 7.5 mm and longer have the full complement of 3. As in the dorsal fin the most posterior spinous ray can be identified by its relative height. The full complement of 6–7 soft rays is present in larvae 6.8 mm and larger. As in the dorsal fin, the ultimate soft ray is bifid. All but 2 of the 30 specimens had 7 soft rays.

Formation of the caudal fin had already begun in our smallest specimens which are undergoing notochord flexion. Flexion is complete at 7.5 mm. Although juveniles have 2 superior and 2 inferior hypurals the more primitive complement of 3 + 3 hypurals is evident during the larval stage. In juveniles, the superior hypurals consist of a broad inner and a small upper bone; the inferior hypurals comprise a broad inner bone and a narrow lower bone, the parhypural, which we have included in our count of hypurals. These broad inner bones each start from two centers of ossification. In the superior group, the three hypurals start to ossify independently. The uppermost, a small hypural, forms rather late, since it was first observed as a cartilage at 10.6 mm and was not ossified until about 12.8 mm. The other two hypurals are evident on the smallest stained specimen, 6.2 mm. They remain as distinct bones on 6.2- to 7.7-mm specimens and then fuse, initially at their distal margins and then gradually inward toward the ural centrum; fusion was complete by ~17 mm. The inferior group also forms from three centers. On the 6.8-mm specimen, all three bones are separate and ossifying. The two inner bones are fused at their distal margins on a 7.2-mm specimen, and mostly fused along their lengths by ~8.2 mm; however, complete fusion can be delayed until ~17 mm. All hypurals are autogenous (separate from the ural centrum). In that it retains a hemal arch and has a pair of long, thin "parhypuropophyses," the lower hypural of the inferior group could be characterized as a typical "parhypural."

The 8+7 principal caudal rays, countable on the smallest specimen, are supported exclusively by the hypural bones; the superior hypurals support the 8 rays

TABLE 7. Change in the mean number and range of ventral midline melanophores in larvae of *S. melanostomus* from midwater trawl collections.

Size range (mm)	No. specimens	$\bar{x} \pm$ SD	Range
6.0–6.9	12	7.3±1.30	4–9
7.0–7.9	26	5.2±2.53	1–10
8.0–8.9	16	3.8±2.81	0–9
9.0–9.9	9	2.3±1.87	0–5
10.0–10.9	10	1.8±1.99	0–5
11.0–11.9	4	2.8±2.63	0–5
12.0–12.9	13	0.5±0.97	0–3
13.0–13.9	15	0.1±0.26	0–1

of the upper lobe and the inferior hypurals support the 7 rays of the lower lobe.

The procurrent caudal rays form gradually. Two dorsal and 2 ventral procurrent rays were detectable on the 6.2-mm specimen; the lower value for the full complement of procurrent rays, 9 dorsal and 9 ventral, was developed on a 13.2-mm specimen, and the more usual complement of 9 dorsal and 10 ventral rays on a 14.7-mm specimen. The range in larger specimens is 9 or 10 dorsal and 9–11 ventral. The ventral procurrent caudal rays are supported by the spatulate elongated hemal spines of the two vertebrae immediately anterior to the ural; the dorsal procurrent caudal rays are supported by the three epural bones and the spatulate, elongated neural spine of the second vertebra anterior to the ural. The reduced neural spine of the vertebra adjacent to the ural forms at 10.6 mm but is too short to enter into support of the procurrent rays. Note that both hemal spines that support ventral procurrent caudal rays develop autogenously, separate from their centra, but appear to be secondarily ossified to their centra in later life-history stages.

The ural centrum, a long moderately tapered bone with a truncate termination, is beginning to ossify on the 6.2-mm specimen. On this specimen, all vertebral centra except the three immediately anterior to the ural centrum are ossifying; by 7.5 mm all 26 vertebral centra are ossifying. The three epurals are first seen as cartilage on a 9.4-mm specimen and are ossified on a 13.2-mm specimen. The single pair of uroneurals appears on a 10.6-mm specimen and is well developed by 13.2 mm.

PIGMENTATION

The initial pigment pattern of *S. melanostomus* larvae is known from specimens reared in the aquarium (Moser et al. 1977). The dorsal and lateral surfaces of the gut are covered with melanophores. A ventral midline row on the tail contains fewer melanophores than in any other species presently known (mean of 8, with a range of 4–11, for 27 specimens counted). The pectoral fin is partially covered with a patch of fine melanophores. Most specimens examined had one or two spots on the nape, as many as 8 melanophores on the dorsal aspect of the head, and a strong patch at the mandibular symphysis, often extending onto the gular region. About half of the reared specimens had a linear patch of melanophores at the posterior aspect of the jaw, a unique placement for the species of *Sebastes*, insofar as presently known.

With further development, the number of melanophores in the ventral midline is reduced (Table 7) and they are lacking in larvae longer than 14.0 mm. The pigment over the gut is augmented and forms a solid sheet over the gut. Pigment is added to the brain and forms a solid covering in larvae longer than 11.0 mm. The blotch at the symphysis of the lower jaw enlarges to cover the oral valve and remains prominent throughout the larval period. It becomes diffuse and gradually weaker in pelagic juveniles and is absent occasionally in specimens longer than 18.0 mm. The pigment streak originally posterior to the jaw becomes more pronounced and becomes located above the anterior half of the maxillary throughout the larval and pelagic juvenile stages. A distinctive patch of melanophores begins to form on the upper region of the opercle in 6-mm larvae. The patch enlarges throughout the larval period. In pelagic juveniles it covers the entire opercle and becomes confluent with the dorsal head pigment. Pigment develops on the cheek at the posteroventral corner of the orbit in larvae as short as 10.8 mm. It is variously present or absent in larvae as long as 13.0 mm and present, usually as a triangular patch, in specimens up to 19.0 mm. In larger pelagic juveniles the patch usually extends anteriad beneath the eye. Pigment patches in the nasal region are present in about half the larvae longer than 13.0 mm. In pelagic juveniles the patches enlarge and become diffuse over the entire nasal region.

The most striking pigmentation is the pattern of melanistic bars that develops on the body. The anterior bar begins to form in larvae as short as 11.3 mm. Either a patch of melanophores that extends upward from the gut region or a patch that extends downward from the base of the dorsal fin, or both, are present. Although the smallest larvae in which these patches become confluent to form a complete band measures 12.3 mm, larvae as long as 14.7 mm may not have a complete band. The band has a consistent width, extending ventrad in a zone between the 3rd or 4th to the 7th or 8th spinous dorsal. A bar begins to form beneath the soft-dorsal fin in larvae as short as 14.4 mm. It is present in about half of the larvae between 14.4 and 16.0 mm as a patch of melanophores or saddle extending ventrad from the fin base. It was observed in all but 4 of 21 pelagic juveniles between 16.0 and 18.2 mm long and in all specimens longer than this. There is a gradual ventrad progression of the saddle, and in late pelagic juveniles a complete band is formed with pigment developing dorsad from the anal fin base. A third band begins to form on the caudal peduncle in pelagic juveniles as short as 20.7 mm. Initially it is a lateral blotch but enlarges to form a complete band in specimens longer than 32.2 mm.

The development of background pigment on the unbanded regions of the trunk is a gradual process that begins in larvae as short as 13.5 mm in which one to several melanophores appear forward of the anterior band. These melanophores become more extensive in later larvae, and the entire area anterior to the band begins filling in with pigment in pelagic juveniles to become solidly covered in most specimens longer than 19.0 mm. The gradual filling in of the unpigmented areas between the posterior bands begins at ~32.5 mm long and progresses so that the largest pelagic juvenile is completely pigmented with the bands merely accentuated.

The fins are also characteristically pigmented. In newborn larvae the pectoral fin blades are evenly covered with fine melanophores. As the fin rays develop, the melanophores become distributed on the interradial membranes, with heavier pigmentation on the distal margins of the blades. The medial surfaces of the fin bases are heavily pigmented. At ~7.5 mm an unpigmented zone begins to form between the distal margin and the proximal half of the fin blade. At ~9.0 mm the pigment at the distal margin begins to diminish while pigment remains in an arc-shaped basal zone that extends onto the dorsal margin of the fin. At the beginning of the pelagic juvenile stage the pigment along the dorsal margin of the fin begins to recede, leaving a basal bar that becomes accentuated in late-stage pelagic juveniles. In early larvae the membranes between the pelvic rays become covered with melanophores, and the distal margins of the fins are accentuated. At ~9.0 mm the pigment begins to recede from the margins and with further development becomes restricted to the proximal region of the fins.

Characteristic blotches develop on the dorsal and anal fins of pelagic juveniles. At the beginning of the pelagic juvenile stage a large blotch develops as a dorsad extension of the anterior pigment bar and at its maximum development in late-stage pelagic juveniles occupies the basal half of the fin in a zone extending from the 3rd to the 6th spinous ray. Concomitantly, a small blotch develops anteriorly on the membrane between the 1st and 3rd spinous rays. At ~26.0 mm a large blotch develops as a dorsal extension of the posterior pigment bar and another blotch forms between the 9th and 12th spinous dorsal rays. At ~30.0 mm a blotch forms on the anal fin and at maximal development extends from the 2nd spinous ray to the 7th soft ray.

Distribution

Confusion surrounds our knowledge of the latitudinal range of *S. melanostomus*. Miller and Lea (1972) listed the southern limit as Cedros Island, Baja California (28°15′N). Our records extend this southward to off Punta Abreojos (26°06′N, 114°05′W). On the basis of biochemical identification Tsuyuki and Westrheim (1970) suggested that the northern limit lies to the south of British Columbia. Barsukov (1968) reported this species from the Bering Sea and synonymized it with the Japanese species *S. iracundus*. If he is correct, *S. melanostomus* has the greatest latitudinal range of any species of *Sebastes*. Tsuyuki and Westrheim (1970) pointed out the taxonomic complexities of the *S. melanostomus* species group and their estimate of the northern limit of this species may well be correct.

Little is known about the bathymetric distribution of *S. melanostomus*. Depth range for 10 benthic collections of juveniles and adults made off southern and Baja California was 183–448 m with a mean weighted to catch rate of 302 m (SIO Fish Collection). Miller and Lea (1972) listed the maximum known depth of *S. melanostomus* as 549 m, making this one of the deepest living of all *Sebastes*. For this reason, blackgill rockfish are rarely taken by commercial and recreational fishermen off southern California. Their comparative abundance in midwater trawl samples in this area (Table 1) suggests that the small catches of adults may not reflect true abundance and that blackgill rockfish may represent a potential deep-water fishery.

The frequent and widespread occurrence of larvae and pelagic juveniles in midwater trawl samples taken over deep coastal waters (Fig. 1) and their need to reach more shoreward shallow areas for settling suggests a distinct life-history strategy for *S. melanostomus* and for the other rockfish species taken with it.

The peak month for birth of *S. melanostomus* larvae off southern California is February (J. LaGrange personal communication). Like other species of *Sebastes*, larvae of *S. melanostomus* inhabit the upper mixed layer and are seldom taken below 100 m (Ahlstrom, 1961). After completing larval development at ~16 mm long they transform into pelagic juveniles and live in the midwaters over coastal basins during summer. Large *S. melanostomus* larvae appear in midwater trawls from April to August (Fig. 8). Pelagic juveniles begin to appear in June and are found in increasingly larger sizes through October. Examination of daily growth rings on the otoliths of specimens taken from albacore stomachs revealed an age of 47 d for a 15.0-mm larva and 101 d for a 30.4-mm pelagic juvenile, the largest one available (Fig. 9). Pelagic juveniles are therefore ~3½ mo old when they approach the size for settling. The size threshold for settling to the bottom is ~36.0 mm, judging from a newly transformed specimen of that size taken in an otter trawl off Scripps Institution of Oceanography (La Jolla, Calif.) at 265–356 mm. Pelagic juveniles of this size appear in midwater trawls in September and October and either migrate or are transported shoreward to water of appropriate depth for settling. Two discrete depth tows, one at 200 m in August and another at 250 m in October, contained pelagic juveniles of 30.1 and 32.5 mm, respectively, suggesting that horizontal migration or transport of pelagic juveniles occurs in this depth range. This strategy appears to be shared with *S. aurora* and a number of

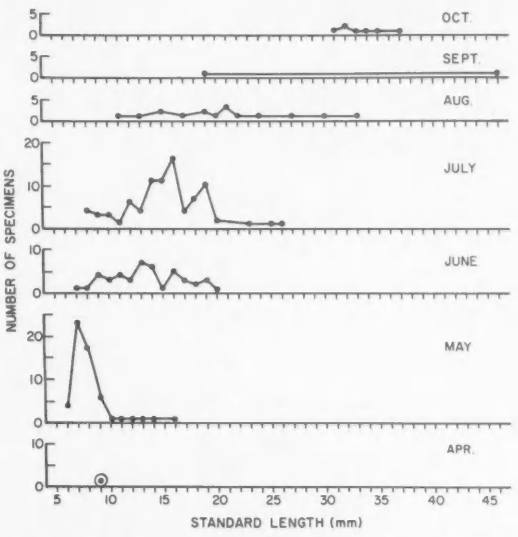


FIG. 8. Composite monthly size frequencies for larvae and pelagic juveniles of *S. melanostomus* from midwater trawls.

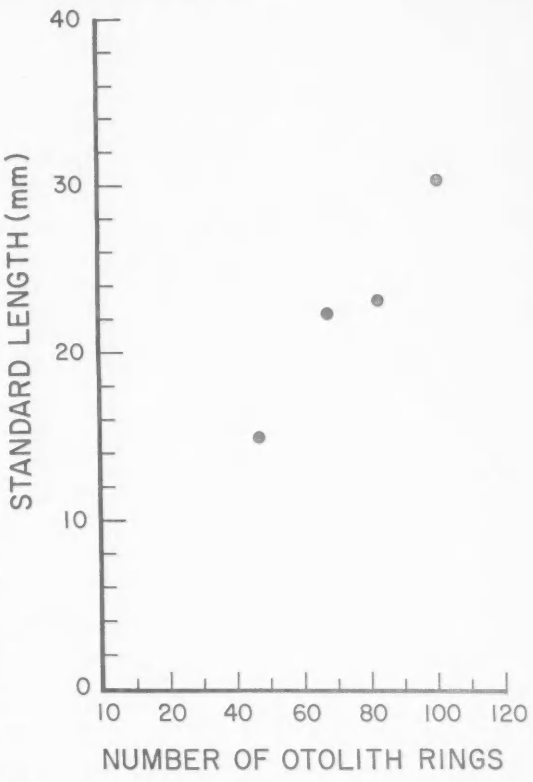


FIG. 9. Age–length relationship of *S. melanostomus* based on counts of daily growth rings of sagittae.

species of the subgenus *Sebastomus*. Interestingly, all of these species have strong dark bands alternating with almost transparent regions on their bodies, possibly a protective pattern that serves to break up their body outline during their pelagic life. A similar strategy involving a midwater pelagic juvenile stage is found in *Sebastolobus altivelis*; however, adults of that species inhabit the deep coastal basins and juveniles can reach the adult habitat by descending vertically (Moser 1974).

A different strategy is employed by the splitnose rockfish, *Sebastes diploproa* (Mitchell and Hunter 1970; Boehlert 1977). Larvae are released from February to July and appear in surface waters upon reaching a length of ~10 mm. They are recruited to drifting masses of kelp and flotsam where they grow to a maximum of 50 mm long. These juveniles develop a solid background pigmentation with faint bars, and the fins have contrasting dark and clear areas that would appear to disguise them in the kelp and midwater habitat. Since the smallest benthic specimens are ~30 mm long, emigration from surface waters must occur in a length range of 30–50 mm. Catches from discrete midwater hauls indicate that emigrating pelagic juveniles descend to a depth of 200–250 m and migrate horizontally until they reach bottom, at which time they are ~1 yr old.

The bocaccio, *S. paucispinis*, exhibits a third strategy (Moser 1967). Planktonic larvae attain a size of ~30 mm and then migrate shoreward to their early juvenile habitat in kelp and eelgrass beds. Juveniles from these habitats have a striking pattern of irregular bars and pigment saddles that provide a mottled appearance. At the end of their 1st yr they begin to move into deeper water, and a pattern of small spots has replaced the mottling.

The life-history strategies described here are probably only a fraction of those utilized by wide-ranging planktonic larvae of rockfishes to reach appropriate habitat for settling. At present the larvae of only about a half dozen species can be identified from plankton samples and, with present techniques, the larvae of a substantial number of species will not be differentiable. Estimation of spawning biomass from ichthyoplankton surveys will therefore be limited to a portion of the rockfish fauna. Likewise, the commercial and recreational fisheries sample a limited number of species over a portion of their habitat. An alternative is to sample juvenile stages. Because of the diversity of strategies and habitats, each species may be vulnerable to collection at some time during the juvenile period, either by trawl, trap, or predator. Additionally, sampling of juvenile stages provides the potential for predicting year-class strength. *Sebastes melanostomus* provides a clear example of a species with a special pelagic juvenile stage that is vulnerable to sampling by midwater trawl. Re-

search on the life histories of other rockfish species may provide similar opportunities for resource assessment.

Acknowledgments

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Effects of Aroclor® 1248 and 1260 on the Fathead Minnow (*Pimephales promelas*)

D. L. DeFoe, G. D. Veith, and R. W. Carlson

U.S. Environmental Protection Agency, Environmental Research Laboratory-Duluth, Duluth, Minn. 55804, USA

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Fathead minnows were exposed to Aroclor® 1248 and 1260 in flow-through bioassays to determine the acute (30-d) and chronic (240-d life cycle) effects on the larvae and adults, as well as the bioconcentration of the mixtures of PCBs in the fish. Newly hatched larvae (<8 h old) were the most sensitive; the calculated 30-d LC50 was 4.7 μg/L for Aroclor 1248 and 3.3 μg/L for Aroclor 1260. Reproduction in fathead minnows occurred at concentrations as high as 3 μg/L for Aroclor 1248 and 2.1 μg/L for Aroclor 1260, concentrations that significantly affected larval survival. The 20% reduction in the standing crop in the second-generation fish at concentrations as low as 0.4 μg/L was due to the death of the larvae soon after hatching. The bioconcentration factor for PCBs was independent of the PCB concentration in the water; in adult females at 25°C it was $\sim 1.2 \times 10^5$ for Aroclor 1248 and 2.7×10^5 for Aroclor 1260. Females accumulated about twice as much PCBs as the males because of the greater amount of lipid in the female. Exposed fish placed in untreated Lake Superior water eliminated <18% of the body burden after 60 d.

Key words: PCBs, bioassay, bioconcentration, chronic toxicity, embryo-larval, depuration

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Des larves et des adultes de tête-de-boule (*Pimephales promelas*) ont été exposés à l'Aroclor® 1248 et 1260, en vue du dosage biologique en conditions dynamiques de la toxicité aiguë (30 jours) et chronique (cycle biologique de 240 jours) et en vue du dosage des mélanges de BPC dans leurs tissus. Les larves nouvellement écloses (moins de 8 h) se sont montrées les plus sensibles; la CL50 après 30 jours était de 4,7 et de 3,3 μg/L pour l'Aroclor 1248 et 1260, respectivement. On a observé la reproduction de cette espèce à des concentrations s'élevant jusqu'à 3 et à 2,1 μg/L pour l'Aroclor 1248 et 1260 respectivement, lesquelles ont influé de façon significative sur la survie des larves. La diminution de 20% du stock actuel des poissons de la deuxième génération, à des concentrations de 0,4 μg/L était due à la mortalité des larves peu après l'éclosion. Le facteur de bioconcentration des BPC était indépendant de leur concentration dans l'eau; chez les femelles adultes et à 25°C, il était d'environ $1,2 \times 10^5$ pour l'Aroclor 1248, et de $2,7 \times 10^5$ pour l'Aroclor 1260. La quantité de BPC accumulés chez les femelles était environ le double de celle des mâles, à cause de la teneur en lipides plus élevée chez les femelles. Les sujets placés dans de l'eau non traitée du lac Supérieur après ces essais ont éliminé moins de 18% de leur teneur en BPC en 60 jours.

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The purpose of this study was to determine the acute and chronic effects of Aroclor® 1248 and Aroclor® 1260 on the fathead minnow and to discuss the bioaccumulation of PCB residues in these test fish. (Aroclor® is the trade name for mixtures of chlorobiphenols manufactured in the U.S. by Monsanto Company, St. Louis, Mo.) Such information is necessary for the establishment of water-quality criteria for polychlorinated biphenyls (PCBs). Because of the complexity of PCB mixtures, there is a tendency to establish criteria for the generic term, PCB, without regard for the degree of chlorination. Previous studies (Nebeker et al. 1974) have shown that Aroclor 1242, Aroclor 1248, and Aroclor 1254 are not substantially different in toxicity to aquatic organisms.

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Materials and Methods

Biological Methods

The bioassay procedures have been described previously (National Water Quality Laboratory 1972); we used the

TABLE 1. Survival, growth, and standing crop of fathead minnow larvae after acute exposure (30 d) to Aroclor 1248.

Mean measured concn (μg/L)	Replicate	Larval survival (%)	% control	Wt (mg) ± SE	% control	Total length (mm) ± SE	% control	Mean standing crop (mg)	% control
8.5	A	0	0	0	0	0	0	0	0
	B	0		0		0		0	
4.4	A	23	56[a]	27±10	34[a]	13.3±1.4	70[a]	192	20[a]
	B	70		38±4		15.9±0.4		792	
	C	53		34±4		15.0±0.6		536	
	D	53		46±4		16.7±0.6		738	
2.2	A	93	98	95±6	78	21.0±0.5	93	2650	79
	B	80		73±6		19.4±0.4		1760	
1.1	A	90	102	107±8	102	22.2±0.5	102	2880	105
	B	90		112±8		22.2±0.5		3030	
0.0 (control)	A	87	100	93±9	100	20.3±0.7	100	2420	100
	B	90		122±8		23.2±0.3		3300	

[a]Values showing significant decrease ($P = 0.05$) from control with analysis of variance and Dunnett's test.

injector system described by DeFoe (1975) in which equal quantities of the toxicant dispersant could be added to all test chambers. The test animal, the fathead minnow (*Pimephales promelas*), was taken from the laboratory culture unit. The daily feeding procedure consisted of one feeding of a mixture of three commercial dry fish foods and a second feeding of live brine shrimp. In addition, the adult fish were fed live *Daphnia magna* once each week.

Acute tests were conducted with fathead larvae <8 h old. Exactly 30 larvae were placed in each tank, and the survival and growth were recorded after 30 d.

Chronic tests were initiated by placing 65–75 embryos into incubation cups in the large adult chambers. After hatching, 50 larvae were released into each tank; the population was thinned after 30 d. The final thinning to 15 juvenile fish per tank was completed with the 66-d-old fish, and the standard length was recorded (McKim and Benoit 1971). The excess fish not used in the remainder of the 240-d test were placed in clean Lake Superior water for a residue depuration study.

Five spawning substrates consisting of 6–8-cm longitudinal half-sections of brown glass bottles were placed in each tank, and the excess males were removed after all substrates were occupied by a mature male. During spawning the embryos were removed each morning by using the method of Gast and Brungs (1973). The embryos were transferred to the incubation cups in the adult tank to determine the hatching success.

CHEMICAL METHODS

Water samples (100 mL) were taken daily, and the composited water sample from 5 d was extracted in separatory funnels with 150 mL petroleum ether. The extracts were concentrated for gas–liquid chromatography (GLC) analysis. The mean recoveries for the water analysis were 76% for Aroclor 1248 from 18 spiked (0.3–6.1 μg/L) samples and 88% for Aroclor 1260 from 12 spiked (0.1–3.0 μg/L) samples. Fish were analyzed for PCBs as described by Veith et al. (1977). The recovery of standard additions of the PCB mixtures indicated that the recovery for this procedure was ~90%. Concentrations were calculated by using the recovery values, and only the mean recovery-corrected concentrations are presented.

With Aroclor 1248 the concentration mean ranged from 1.1 to ~8.5 μg/L in the acute tests and from 0.1 to 3.0 μg/L in the chronic tests. The standard errors were generally <20% of the mean. The PCBs in the acute tests with Aroclor 1260 ranged from 1.3 to 9.0 μg/L, whereas those in the chronic tests ranged from 1.0 to 2.1 μg/L. The number of analyses for both Aroclors was 13–20 for each concentration. The concentration of PCBs in both studies varied <15% after the diluter reached a steady-state operation.

The Lake Superior water used in the tests had a mean hardness of 43.6 mg/L (as $CaCO_3$) and a mean alkalinity of 41.1 mg/L (as $CaCO_3$). The pH varied between 7.10 and 7.85 during the test, and the arithmetic mean of the pH values was 7.52 ± 0.02. The dissolved oxygen varied from 4.6 to 8.8 mg/L with a mean concentration of 7.0 ± 0.07 mg/L (APHA et al. 1965).

Results and Discussion

ACUTE TOXICITY

All larvae (<8 h old) died when they were exposed for 30 d to 8.5 μg/L Aroclor 1248 (Table 1). Forty-four percent of the larvae died at 4.4 μg/L, and no effect on survival was evident at 2.2 μg/L. The calculated 30-d LC50 from these data was 4.7 μg/L. The weight, length, and standing crop (mean weight times number surviving) of test fish increased slightly when exposed to 1.1 μg/L, but decreased at the higher PCB concentrations. When exposed to 4.4 μg/L Aroclor 1248, the mean larval weight was reduced 66%, the mean length (total) was 30% less, and mean standing crop was 80% less than that of the controls. The mean standing crop in the 2.2 μg/L exposure was reduced to 79% of the control, due largely to a 22% reduction in mean weight.

All the test fish died during the 30-d exposure to

TABLE 2. Survival, growth, and standing crop of fathead minnow larvae after acute exposure (30 d) to Aroclor 1260.

Mean measured concn (μg/L)	Replicate	Larval survival (%)	% control	Wt (mg) ± SE	% control	Total length (mm) ± SE	% control	Mean standing crop (mg)	% control
9.0	A	0	0	0	0	0	0	0	0
	B	0		0		0		0	
4.0	A	33	31[a]	60±13	70[a]	18.0±1.2	89[a]	596[a]	22[a]
	B	23		62±14		17.9±1.2[a]		434[a]	
1.3	A	87	98	69±8	82	18.4±0.7[a]	92[a]	1790[a]	79[a]
	B	87		72±7		19.0±0.7[a]		1880[a]	
0.0 (control)	A	83	100	71±8	100	19.3±0.7	100	1770	100
	B	97		100±7		21.2±0.4		2910	
	C	87		92±8		20.6±0.6		2380	
	D	87		84±9		20.0±0.6		2190	

[a]Values showing significant decreases ($P = 0.05$) from control with analysis of variance and Dunnett's test.

9.0 μg/L Aroclor 1260 (Table 2). Sixty-nine percent of the larvae died at 4.0 μg/L, and no effect on survival was evident at 1.3 μg/L. The calculated 30-d LC50 for Aroclor 1260 from these data was 3.3 μg/L. The weight, length, and standing crop of the young fish exposed to 4.0 μg/L were reduced by 30, 11, and 78%, respectively. The standing crop of the fish exposed to 1.3 μg/L was reduced by 21%.

The results on survival of fathead minnows in these tests agree well with those of Nebeker et al. (1974), who found that all fish died rapidly at 18 μg/L Aroclor 1248 and 25% at 5.1 μg/L. In this study after 30-d exposure to Aroclor 1248, all larvae died at 8.5 μg/L, 44% died at 4.4 μg/L, and no effect on survival was apparent at 2.2 μg/L.

CHRONIC EFFECTS

Reproduction occurred at all tested concentrations of Aroclor 1248 up to 3.0 μg/L; however, the great variability in the data precluded the disclosure of any definite trends. Also, the hatching of embryos was equally successful at all test concentrations (3.0–0.1 μg/L). Embryos transferred from Lake Superior control water to 3.0 μg/L of Aroclor 1248 hatched with as much success as those remaining in the control water.

The reproductive success of fathead minnows measured as egg production per female exposed to Aroclor 1260 was ~1000 at concentrations from 0.1 to 2.1 μg/L. No trend was discernible in the data. Likewise, the hatching success of the embryos ranged from 126% of the control at 0.1 μg/L PCB to 90% of the control at 2.1 μg/L of Aroclor 1260. The mean hatching success of three groups of embryos transferred from the control tanks to 2.1 μg/L Aroclor 1260 was 45 ± 13%, or 27% below the hatch success of the control.

Nebeker et al. (1974) have shown that reproduction in the fathead minnow occurs at concentrations as high as 1.8 μg/L Aroclor 1254 and 5.4 μg/L Aroclor 1242. Since reproduction occurred at 3 μg/L in this study and the 30-d LC50 is 4.7 μg/L, the toxicity of Aroclor 1248 is apparently greater than that of Aroclor 1242 and less than that of Aroclor 1254.

The 30-d LC50 for Aroclor 1260 with fathead minnow larvae was 3.3 μg/L, indicating that the acute toxicity of Aroclor 1260 is slightly greater than that of Aroclor 1248. Although 4.0 μg/L of Aroclor 1260 reduced the weight, length and standing crop of the young fish after 30 d, 2.1 μg/L of Aroclor 1260 reduced the length of the 66-d-old fish only 8% (significant at $P = 0.05$) of the control, and no effect on weight or length of the fish was observed after 237 d at 2.1 μg/L. As with Aroclor 1248, this study with Aroclor 1260 showed no discernible effect on the reproductive success of fathead minnows exposed to concentrations that approach the 30-d LC50. The data indicate that PCBs do not produce major effects on reproduction at concentrations up to the 30-d LC50 and that the reduced standing crop in a multigeneration study is largely due to the larval mortality. These results are consistent with those of Nebeker et al. (1974), who concluded that fathead minnow larvae were the most sensitive stage in the chronic bioassay of PCBs.

The 30-d survival and growth of F_2-generation (second-generation) larvae in the Aroclor 1248 chronic exposure are shown in Table 3. As was observed with the first-generation larvae, exposure to 0.1 μg/L Aroclor 1248 did not affect survival, weight, or length of the fish after 30 d. However, at greater concentrations the length, weight, and standing crop decreased with increasing concentrations. At 3.0 μg/L a 33% reduction in weight resulted in a 30% reduction in standing crop.

Table 4 presents a summary of the survival and growth of the F_2 generation after 30 d in water containing Aroclor 1260. The weight of the F_2-generation larvae exposed to 2.1 μg/L Aroclor 1260 was 84% that of the control fish, and weight tended to decrease with increasing concentration of toxicant. However, ad-

TABLE 3. Survival and growth of second-generation (F_2) fathead fry larvae after 30-d exposure to Aroclor 1248.

Mean measured concn (μg/L)	Mean survival (%) ± SE	% control	Mean wt (mg) ± SE	% control	Mean length (mm) ± SE	% control	Mean standing crop (mg) ± SE	% control
3.0	78±7.0 $N = 6$	104	98.2[a]±21.1	67[a]	19.6[a]±1.3	84[a]	1504±322.5	70
1.1	86±3.5 $N = 7$	115	105.6[a]±9.5	72[a]	21.4±0.6	92	1807±176.2	84
0.4	78±6.5 $N = 10$	105	117.9[a]±6.9	80[a]	21.7±0.5	93	1866±218.2	87
0.1	81±3.5 $N = 5$	109	138.5±11.0	94	22.2±0.6	95	2334±214.0	104
0.0 (control)	75±6.0 $N = 8$	100	146.7±10.8	100	23.3±0.6	100	2155±168.7	100

[a]Values showing significant decrease ($P = 0.05$) from control with analysis of variance and Dunnett's test.

TABLE 4. Survival and growth of second-generation (F_2) fathead fry larvae after 30-d exposure to Aroclor 1260.

Mean measured concn (μg/L)	Mean survival (%) ± SE	% control	Mean wt (mg) ± SE	% control	Mean length (mm) ± SE	% control	Mean standing crop (mg) ± SE	% control
2.1	89±3.5[a] $N = 8$	120[a]	141.2±7.9	84	23.7±0.4	96	2498±144.0	98
0.7	93±2.0[a] $N = 10$	125[a]	150.0±9.5	89	24.2±0.3	98	2793±220.6	99
0.4	92±3.0[a] $N = 9$	124[a]	152.3±10.1	89	23.4±0.6	94	2770±160.0	108
0.1	97±1.0[a] $N = 7$	131[a]	170.1±8.2	104	25.3±0.7	102	3303±158.2	129
0.0 (control)	74±6.5 $N = 8$	100	169.4±13.6	100	24.8±0.7	100	2558±349.6	100

[a]Values showing significant increase ($P = 0.05$) from control with analysis of variance and Dunnett's test.

verse effects on length or standing crop were not observed in this chronic test, and the mean standing crop of the larvae in 2.1 μg/L Aroclor 1260 was 98% that of the control fish.

BIOACCUMULATION OF PCBs

The composition of the PCB residues in fathead minnows exposed during the bioassays were essentially identical to the composition of the toxicants used in the bioassay system. A chromatogram of Aroclor 1248 used in the exposure is shown in Fig. 1A; the major peaks and shoulders of the chromatogram are numbered 1–16. A chromatogram of the Aroclor 1248 residue in fish after ~200 d of exposure (Fig. 1B) shows that the composition of the residue is similar to that of the standard Aroclor 1248. The major components labeled 3–16 have essentially the same relative percentages in both mixtures. Subtle changes appear to be taking place in the fish, however, as shown by the reduction of components 1 and 2 in the chromatogram.

The changes in the composition of the PCB isomers are more pronounced in fish that were exposed for ~66 d and then placed into clean Lake Superior water for 34 d. In a chromatogram of residues from these fish the major components are clearly 3, 5, 6, 8, 11, 12, and 13, but the relative increase in the later-eluting components in the mixture is evident. The most noticeable changes are as follows: the reduction of peaks 1, 2, and 4; the change in the doublet-labeled peaks 6 and 7, which now look like a single, unresolved component; a similar effect with peaks 8 and 9; and the relative increase in peaks 11, 12, and 13 relative to the Aroclor 1248 standard. Unlike the Aroclor 1248 exposure, a comparison of chromatograms of the Aroclor 1260 residue in fish with reference standard Aroclor 1260 on a component basis showed that the composition of the PCB mixtures was essentially identical.

The residues in the fish reached an apparent steady state after ~100 d of exposure and growth, and the uptake could be approximated by a first-order uptake mechanism. The concentration of PCB in the female was twice as large as that in the male (Fig. 2). The concentration in the female fish on a wet-weight basis

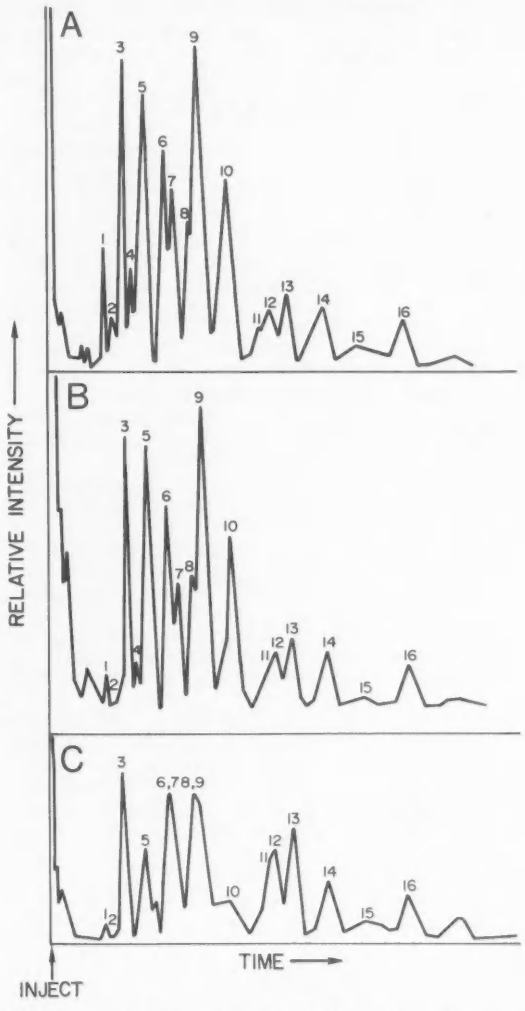

FIG. 1. GLC chromatograms of (A) reference Aroclor 1248, (B) Aroclor 1248 residues in fish after 200-d exposure, and (C) fish residue after 34 d in clean water.

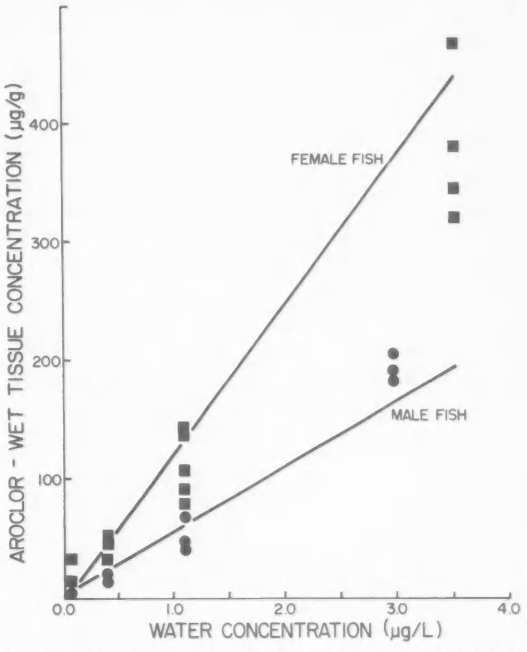

FIG. 2. Variation of Aroclor 1248 residues in male (circles) and female (squares) fish (wet weight) with concentrations in water after 250-d exposure.

was much more variable than that of the male, presumably because of a variable lipid content of the female at the termination of the test.

Although the apparent mechanisms for the uptake in Aroclor 1248 and 1260 appear to be similar, greater body burdens resulted from the Aroclor 1260 exposure. Males contained ~190 µg/g of Aroclor 1248 after being exposed to 3 µg/L for 250 d. This corresponds to an apparent bioconcentration factor (concentration in fish to concentration in water) of ~60 000. Male fish in the Aroclor 1260 exposure contained ~350 µg/g of Aroclor 1260 after being exposed to 2.1 µg/L of Aroclor 1260 for a bioconcentration factor of 160 000. The bioconcentration factors for females were 120 000 and 270 000, respectively. Thus more highly chlorinated PCB mixtures are bioconcentrated to a greater extent in the fish.

The wet-weight residue of Aroclor 1248 in fathead minnow tissue was directly proportional to the concentration of Aroclor 1248 in the water, and the slope of the uptake curve is about twice as great for the female fish as for the male fish (Fig. 2). However, the concentration of Aroclor 1248 and Aroclor 1260 is essentially the same in the males and females when expressed on a lipid basis and is directly proportional to the concentration of PCBs in the water (Fig. 3).

The depuration study showed that the concentration of PCBs decreased exponentially with respect to time. However, the observed decrease in concentration of PCBs is due to the growth of the fish as well as possible elimination from the fish tissue. Fish exposed to Aroclor 1248 contained a body burden of 176 µg of Aroclor 1248 at the initiation of the elimination study, 147 µg at the end of 14 d, and 143 µg after 28 d. Therefore, only 18% of the original PCB burden had been eliminated in the 28-d elimination study. Fish exposed to Aroclor 1260 contained ~100 µg/fish, and this value decreased to 85 µg/fish, or 15%, after 42 d of elimination. Because of the large variation in the PCB concentrations in fathead minnows from the same tank, the 10–20% decline in total body burden is insufficient to indicate PCB elimination during this period. These data

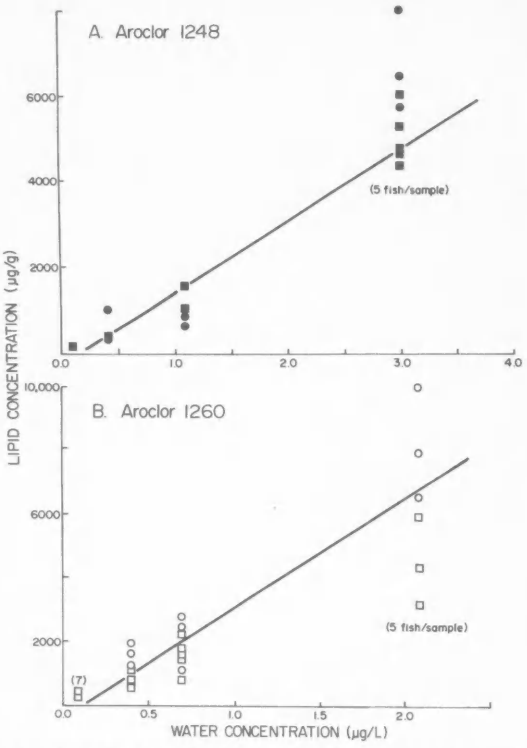

FIG. 3. Variation of (A) Aroclor 1248 and (B) Aroclor 1260 residues (lipid basis) in male (circles) and female (squares) fish with concentrations in water after 250-d exposure.

are in agreement with Lieb et al. (1974), who have concluded that Aroclor 1254 was not eliminated from rainbow trout at a measurable rate. Ringer et al. (1972) and Platonow and Karstad (1973) have shown that PCBs are lethal to mink at dietary concentrations of 2.0 and 0.64 µg/g, respectively. Moreover, Barsotti and Allen (1975) have shown deleterious effects on nonhuman primates fed 2.5 µg/g Aroclor 1248. Because of the extremely large bioconcentration factors for PCBs, it is apparent that even at concentrations <0.1 µg/L, which do not measurably affect the fathead minnow, the residues of PCBs in the fish would be extremely hazardous to consumers of the fish.

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Ammonia Quotient in Sockeye Salmon (*Oncorhynchus nerka*)

M. N. KUTTY[1]

Department of Fishery Science, Tamil Nadu Agricultural University, Coimbatore-641003, Tamil Nadu, India

KUTTY, M. N. 1978. Ammonia quotient in sockeye salmon (*Oncorhynchus nerka*). J. Fish. Res. Board Can. 35: 1003–1005.

Ammonia quotients (A.Q., ratio of ammonia excreted to oxygen consumed) were computed from data on daily-fed and starved sockeye salmon (*Oncorhynchus nerka*). In 22-d starved salmon, where a diel pulse in oxygen consumption, but not in ammonia excretion, persisted, the A.Q. was 0.125 at the prepulse stage (0.11 in fed fish); the lowest A.Q. was 0.06 (0.05 in fed fish) at peak oxygen consumption. The highest A.Q. of 0.24 was obtained in fed fish at the peak of ammonia output. Based on a theoretical estimate of an aerobic maximum A.Q. of 0.33, it is estimated that protein oxidation changes from 18 to 38% in starved sockeye and 15 to 73% in fed fish. The latter value is possibly an overestimate because of the involvement of nonoxidative protein breakdown, but this anaerobic involvement in routine metabolism of sockeye may be negligible.

Key words: ammonia excretion, ammonia quotient, *Oncorhynchus nerka*, daily metabolic pattern, protein catabolism, starvation effect, energy utilization, nitrogen-excretion ratio, *Rhinomugil corsula*

KUTTY, M. N. 1978. Ammonia quotient in sockeye salmon (*Oncorhynchus nerka*). J. Fish. Res. Board Can. 35: 1003–1005.

Nous avons calculé les quotients ammoniacaux (Q.A., le rapport de l'ammoniac excrété à l'oxygène consommé) à partir de données recueillies sur des saumons nerka (*Oncorhynchus nerka*) nourris quotidiennement ou privés de nourriture. Chez des saumons privés de nourriture pendant 22 jours et chez lesquels persistait une pulsation nycthémérale de la consommation d'oxygène mais non de l'excrétion ammoniacale, le Q.A. est de 0.125 au stade de prépulsation (0.11 chez des poissons nourris), et le Q.A. le plus bas est 0.06 (0.05 chez des poissons nourris) au maximum de consommation d'oxygène. Chez des poissons nourris, nous avons observé le Q.A. maximum de 0.24 au pic d'excrétion ammoniacale. En se basant sur une estimation théorique d'un Q.A. maximum aérobie de 0.33, on estime que l'oxydation des protéines passe de 18 à 38% chez les saumons nerka privés de nourriture et de 15 à 73% chez des poissons nourris. Ce dernier chiffre est peut-être une surestimation due à la dégradation, par voie non oxydante, des protéines, mais cette participation anaérobie dans le métabolisme de routine du saumon nerka peut être négligeable.

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THE ratio of ammonia excreted to oxygen consumed by fish, originally termed ammonia quotient (A.Q.) by Stroganov (1956), was discussed recently (Kutty 1972; Kutty and Mohamed 1975; Sukumaran and Kutty 1977) as a potent tool for further understanding energy utilization. This possibility is elaborated in the present note on the basis of observations on sockeye salmon (*Oncorhynchus nerka*).

Brett and Zala's (1975, fig. 3) data on nitrogen (ammonia and urea) excretion and oxygen consumption of sockeye salmon were used to work out the A.Q.'s (mole to mole, or volume relation of ammonia excreted to oxygen consumed).

Results and discussion — In sockeye fed once daily there was a daily pulse in oxygen consumption and ammonia excretion: the "peak" oxygen consumption coincided with the feeding time, the initiation of the pulse being almost 4 h before feeding; the "peak" ammonia excretion occurred about 4 h after feeding when 50% gastric evacuation had taken place. The computed A.Q. at peak oxygen consumption was the lowest (0.05) and that at peak ammonia excretion was the highest (0.24). At the prepulse (O_2) stage the A.Q. was 0.11, which can perhaps be taken as the base value.

[1]Present address: Fisheries College, Tamil Nadu Agricultural University, Tuticorin — 628003, T.N., India.

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TABLE 1. Estimates of energy utilization (heat dissipated) in freshwater mullet, *R. corsula* (42 g), under random activity in freshwater at 30°C. Four separate estimates, assuming different substrates used and respiratory quotient (R.Q.) and ammonia quotient (A.Q.) for proteins, are indicated. Calculations are based on data on routine metabolism at 30°C (routine O_2 consumption = 117.7 $mL \cdot kg^{-1} \cdot h^{-1}$; routine R.Q. = 0.91; routine A.Q. = 0.091). The energy value for protein for the first three estimates was taken as 19.13 $J \cdot mL^{-1} O_2$; the corresponding values for carbohydrate and fat for all estimates are according to conventional calculations for mammals.

	Amino acid mixtures			Whole protein (beef) (Lowey's elemental composition)	
	Glycine–histidine μmol ratio of 3:2 (Creac'h 1966) (carp muscle free amino acids)	Lysine–glycine taurine–histidine μmol ratio of 10:17:30:37 (Konosu et al. 1964) (*Mugil cephalus* muscle free amino acids)	Essential amino acids[b] (Halver 1957, 1961) (salmon)	Fish system	Mammalian system
Protein R.Q.	1.24	0.99	0.90	1.00	0.80
Protein A.Q.[a]	0.621	0.478	0.338	0.335[c]	0.268[d]
			$J \cdot kg^{-1} \cdot h^{-1}$ (%)		
Protein	331 (13.9)	427 (17.9)	1252 (52.7)	611 (25.7)	737 (31.1)
Carbohydrate	1038 (43.7)	1256 (52.5)	515 (21.7)	1072 (45.1)	1423 (60.2)
Fat	1009 (42.4)	703 (29.5)	607 (25.7)	691 (29.1)	209 (8.8)
	2378 (100.0)	2386 (99.9)	2374 (100.1)	2374 (99.9)	2369 (100.1)

[a]Ammonia quotient — mole to mole relation of NH_3 excreted to O_2 consumed.
[b]According to essential amino acid requirement of chinook salmon (*O. tshawytscha*) (Halver 1957, 1961; Phillips 1969).
[c]A.Q. value obtained assuming that all N degraded results in NH_3 and all elemental H in protein used for NH_3 formation.
[d]A.Q. value obtained assuming that all N excreted is in the form of NH_3.

In the sockeye starved for 22 d, a diurnal pulse of oxygen consumption alone (though diminished and diffuse) persisted, which broadly agrees in diel pattern with the oxygen-consumption pulse of the fed fish; however, ammonia excretion remained at about the same level over the day and was similar in magnitude to the prepulse rate of the fed fish. The computed A.Q. was 0.125 at the prepulse stage and 0.06 at the peak of oxygen consumption. Thus, there appeared to be a drastic change in substrate utilization in the starved fish. Since nitrogen excretion remained steady throughout the 24 h, the increase in oxygen consumption must have been caused by the increased utilization of carbohydrates and/or lipids. There was no possibility of exogenous nitrogen excretion in this case. Hence, in a starved fish under random (spontaneous) activity, a cycle in substrate utilization was evident. In fed fish the lowest A.Q. coincided with the feeding time and apparently with maximal random (foraging) activity. The initiation of swimming (forced activity) in *Tilapia mossambica* (Kutty 1972; Karuppannan 1972) and *Rhinomugil corsula* (Sukumaran 1976) always coincided with the lowest A.Q. observed. The immediate increase in energy demand in fish is probably always met by utilizing a more labile energy source than proteins (Black 1957; Phillips 1969).

Theoretically, a maximum A.Q. obtainable for aerobic degradation of proteins to CO_2, H_2O, and NH_3 can be estimated. This value can be taken as 0.33 (see Table 1, columns 4 and 5), with which the relative changes in protein utilization (i.e. the involvement of protein metabolism in the diel pattern of total metabolism) can also be estimated.

If under certain circumstances the A.Q. goes above 0.33, it can be taken that anaerobic degradation of proteins or possibly interconversion of substrates definitely takes place. The relative contributions of these two factors are presumably not significant in the present case. Brett and Zala's data show that a minor portion of nitrogen was always excreted as urea. Like the two factors mentioned this may not seriously affect the general theory proposed but only specific levels of metabolic separation.

If A.Q. is below the aerobic maximum value of 0.33 it suggests involvement of other substrates, thus reducing the relative contribution of protein catabolism in energy release. At an A.Q. of 0.06, an estimated 18% ($0.06 \times 100/0.33$) of the total oxygen consumed was used for oxidizing proteins; the remaining 82% of oxygen consumed was accounted for by carbohydrates and/or fats. Thus the data on sockeye show that in the starved fish protein utilization changed from 18 to 38%, assuming again that the oxycalorific differences among substrates would not seriously affect this contention.

After this simpler model of the starved animal one can consider the daily-fed fish in which the interpretation is complicated by the exogenous element in nitrogen excreted. Under the same assumptions one may say that endogenous excreted nitrogen remains the same in the fed and the starved fish. At peak oxygen consumption the A.Q. of the fed fish was only slightly lower than that of starved fish; i.e. 15% of the oxygen consumed (energy derived) is accounted for by protein. At the prepulse (O_2) stage A.Q. was 0.125 and 38% of oxygen consumed was accounted for by protein oxida-

tion. At peak NH_3 excretion (A.Q. = 0.24) protein could account for about 73% of oxygen consumed, but this may be an overestimate, since exogenous-N excretion need not all be aerobic.

The nitrogen could also be excreted by deamination of amino acids (see Foster and Goldstein 1969) and from the adenylate pool (Driedzic and Hochachka 1975), but possibly the role of anaerobic production of ammonia in this case is negligible. This is supported by the fact that the fish had adequate oxygen. Also the A.Q. value was always below 0.33, unlike in the clearly demonstrated anaerobiosis in *T. mossambica*, where the A.Q. was much higher (Kutty 1972).

In this discussion it would have been better to take total-N excretion and oxygen consumption to obtain a "whole" nitrogen quotient (N.Q.), as indeed has been done by Sukumaran (1976). Since, in Brett and Zala's estimates, urea is the only other nitrogenous end product studied that also remains as a minor nonfluctuating component, ammonia alone of the nitrogenous wastes is considered here. Furthermore, A.Q. rather than N.Q. may have an added significance, since ammonia is the nitrogenous end product investigated in much of the excretion studies in fish and is important for ionic regulation and acid–base balance in the aquatic organism (Garcia Romeu and Motais 1966; Maetz and Garcia Romeu 1964; Kutty 1972). Theoretically estimated and observed A.Q.'s (or N.Q.) in fish under various conditions (aerobic and anaerobic) can be expected to give more insight in the use of A.Q. in studies on energy utilization. In this discussion the relative magnitudes of the values discussed are secondary and the enunciation of the concept of the ammonia or nitrogen quotient in energy metabolism studies is given paramount consideration. Brett and Zala's data ideally suit this need.

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Distance Chemoreception and Vision in the Selection of Prey by American Lobster (*Homarus americanus*)

R. W. M. HIRTLE[1] AND K. H. MANN

Department of Biology, Dalhousie University, Halifax, N.S. B3H 4J1

HIRTLE, R. W. M., AND K. H. MANN. 1978. Distance chemoreception and vision in the selection of prey by American lobster (*Homarus americanus*). J. Fish. Res. Board Can. 35: 1006–1008.

Lobsters responded positively to the waterborne odor of intact living crabs (*Carcinus maenas*), sea urchins (*Strongylocentrotus droebachiensis*), and mussels (*Mytilus edulis*). The frequency of response was higher and the response time shorter to crabs than to sea urchins or mussels. Lobsters also responded to the sight of moving crabs or moving sea urchins, but not to the sight of stationary specimens. Crabs are probably more attractive to lobsters because of their odor and their greater activity, compared with sea urchins or mussels.

Key words: lobsters, prey, chemoreception, vision, crabs, sea urchins, movement, odor

HIRTLE, R. W. M., AND K. H. MANN. 1978. Distance chemoreception and vision in the selection of prey by American lobster (*Homarus americanus*). J. Fish. Res. Board Can. 35: 1006–1008.

Le homard réagit positivement à l'odeur, transmise dans l'eau, de crabes (*Carcinus maenas*), d'oursins communs (*Strongylocentrotus droebachiensis*) et de moules (*Mytilus edulis*) vivants et intacts. La fréquence des réponses est plus élevée et le délai dans la réponse plus court dans le cas des crabes que dans celui des oursins ou des moules. Les homards réagissent également à la vue de crabes ou d'oursins en mouvement, mais non d'individus stationnaires. Les crabes offrent probablement plus d'attrait aux homards tant à cause de leur odeur que de leur activité plus grande, par comparaison avec les oursins communs et les moules.

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BREEN and Mann (1976) and Mann (1977) postulated that lobsters exert a predatory control over sea urchins and that when lobster populations are reduced below a critical level sea urchins aggregate and destroy kelp beds; thus productivity in the food chain leading to lobsters is reduced, lobsters are deprived of cover, and stocks can decline disastrously. Evans and Mann (1977) showed that in aquaria lobsters have a 5:1 dietary preference for crabs over urchins, but it was not clear to what extent this resulted from the crabs being unnaturally confined in the tanks and hence unable to make use of their greater mobility to escape the predators.

In this study we attempted to evaluate the sensory basis for choice of prey by lobsters. A distinction was made between the lobsters' reactions to the odor of prey they could not see, and to the sight of prey from which there was no chemical stimulus.

Materials and methods — For the chemoreception experiments the methods used were a modification of those used by McLeese (1973). Twelve undamaged lobsters of 115–160 mm carapace length were acclimated for 2 mo to a 12:12 light–dark cycle with the dark phase starting at 0800, and each was fed 10 g of squid every 2–3 d. They were held in running seawater at ambient temperatures in compartments measuring 60 × 30 × 30 cm deep. They were deprived of visual contact with one another to increase activity and aggressiveness (Dunham 1972; Hoffman et al. 1975). During the experimental period each was fed 5 g of squid every 2 d, and behavior was observed during the lobster's dark period under the far-red light of a 250-W brooder lamp, which does not inhibit activity (Kennedy and Bruno 1961).

Lobsters were tested with three chemical stimuli and a seawater control, presented in random order. The chemical stimuli were prepared by holding live animals in standing seawater for 12 h, then using the water as the stimulus. Crab (*Carcinus maenas*) stimulus and sea urchin (*Strongylocentrotus droebachiensis*) stimulus were prepared by holding the animals at a concentration of 100 g/L. Since mussels (*Mytilus edulis*) remained closed for part of the time, they were held at a concentration of 200 g/L. Stimuli were presented by injecting 25 mL from a syringe, through a 1 m length of plastic hose of 1.5 mm internal diameter, into the

[1]Present address: Department of Geology, McMaster University, Hamilton, Ont. L8S 4M1.

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upstream end of a 0.6 × 0.3 m compartment, at a time when the lobsters were resting at the downstream end. Dilution of the stimulus with time, under the conditions of the experiments, was determined by injection of rhodamine dye and spectrophotometric analysis of changing concentrations with time. The lobsters were observed for 2 min after stimulus addition, and two types of response were noted. If the lobsters moved upstream this was a walking response; if they made inward sweeping movements with the first two pairs of walking legs or moved the pincers of those legs, this was recorded as a feeding response (McLeese 1970).

For the visual experiments, the lobsters were conditioned as before, but 1 wk before the experiments they were fed to satiation, then starved until the end of those experiments. The tests were carried out in a fiberglass tank divided into three lanes, each measuring 1.2 × 0.3 m, by two plexiglass sheets running longitudinally. Over each side lane ran a loop of monofilament line that could be used to move prey specimens at a slow, constant rate. Lobsters were placed in the central lane and induced to rest at one end by providing a one-way flow of seawater. To minimize transmission of vibrational stimuli the lines were suspended on pulleys mounted independently of the tank, and the side lanes were floored with plastic foam. Lighting was designed to simulate conditions at dawn and dusk at 10 m in local bays, and consisted of blue light with maximum intensity at 480 nm, and a range of approximately 400–550 nm. The irradiance in the tank was 0.5–0.7 microeinsteins $\cdot m^{-2} \cdot s^{-1}$.

A lobster was placed in the central lane 1 h before an experiment. For a moving stimulus, a sea urchin or a crab with chelae extended was towed from the downstream end of a side lane to the far end and back again. For a stationary stimulus, a screen was slowly removed from in front of a prey located half way along a side lane. A response was recorded if the lobster oriented itself and walked towards the stimulus being offered. Controls consisted of moving the lines without any prey being attached.

Results — In the chemoreception experiments there was a positive response to water that had been in contact with crabs, mussels or sea urchins. In 30–46% of trials there was a feeding response, while there was never a feeding response in the controls. Walking responses were observed under control conditions, but the percentage of walking responses to the crab stimulus was significantly higher (Table 1). A plot of percentage response against time (Fig. 1) shows that the response to crabs was more rapid than the response to mussels or urchins. Of the lobsters tested 50% responded within 60 s (T_{50} = 60 s) whereas more than 100 s was required for 50% to respond to mussels or urchins, the difference being significant at the 0.5% level of probability.

The results are complicated by the fact that as time progressed the relative concentration of stimulus was reduced (Fig. 2). There was a linear decline in log concentration for about 75 s, after which the concentration remained approximately constant for a further 45 s. From this we may infer that the response to crabs, for which the T_{50} was 60 sec, tended to occur at higher relative concentrations of stimulus than the response to urchins or mussels.

In the visual experiments there was 100% response to moving urchins and 90% response to moving crabs; the difference was not significant (Table 2). Of 10 trials with stationary urchins and 10 with stationary crabs, there was only one response.

TABLE 1. Percentage response of lobsters to stimulation with water that had been held in contact with various prey species, or with plain seawater control. Asterisks show significance of difference between treatment and control (*t*-test): $^{**}P < 0.1\%$; $^{*}P < 0.5\%$.

	Crabs (n = 27)	Urchins (n = 28)	Mussels (n = 26)	Control (n = 22)
Walking response	63**	29 NS	23 NS	18
Feeding response	33	30	46	0
Either response	70*	54*	54*	18

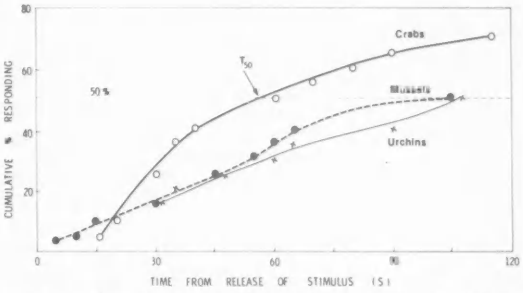

FIG. 1. Cumulative percentage of lobsters in all trials responding to odor of crabs, mussels, and sea urchins, plotted against time.

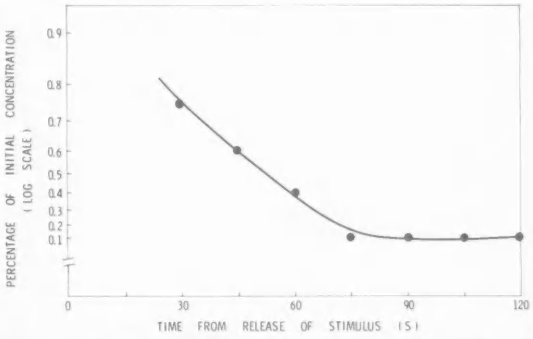

FIG. 2. Pattern of decay of concentration of a dye released to simulate odor stimuli.

Discussion — Lobsters clearly are sensitive to the odor of intact crabs, urchins, and mussels, showing a feeding response in 30–46% of trials. When McLeese (1973) carried out similar experiments he obtained much more infrequent responses, and concluded that

TABLE 2. Response of lobsters to stimulation by moving or stationary prey species, or to movement of apparatus with no prey attached.

	Crabs	Urchins	Controls	
	No. positive (n = 10)	No. positive (n = 10)	No. of trails	No. positive
Moving	9	10	10	1[a]
Stationary	1	0	—	—

[a]Oriented to wrong lane.

lobsters responded weakly or not at all to the odor of intact prey. For crabs and sea urchins the concentration of prey and hence the initial concentration of chemical stimulus was the same in both investigations. However, McLeese (1973) used larger experimental containers and estimated that the stimulus was usually diluted to 0.1–0.2% of the initial concentration by the time it reached the lobsters, compared with 0.1–0.8% in the present studies. He repeated the experiments with concentrated extracts of prey, and still obtained a low response (13%) with sea urchins. We cannot explain this difference.

Lobsters are also sensitive to the sight of a moving object, responding to a moving urchin as readily as to a moving crab. Since in nature crabs move faster than urchins, and since there is a faster and more frequent response by the lobsters to the odor of crabs, we may conclude that on both counts crabs are more attractive to lobsters.

Our present understanding of the role of lobsters as predators on sea urchins and crabs is that when lobsters are confronted with a choice between an urchin and a crab, they show a clear preference for the crab, and will take it if they can catch it. However, Evans and Mann (1977) also showed that when sea urchins outnumber crabs by 10:1 or more, the lobsters will eat about two urchins for every crab since the urchins are easier to catch. In most situations on the Atlantic coast of Nova Scotia the ratio of urchins to crabs is about 20:1 to 30:1 (N. Drummond, Department of Biology, Dalhousie University, personal communication), so presumably urchins outnumber crabs in the diet of lobsters in spite of the preference for crabs.

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Fish Cell Lines: Comparisons of CHSE-214, FHM, and RTG-2 in Assaying IHN and IPN Viruses

R. K. KELLY, B. W. SOUTER, AND H. R. MILLER

Department of Fisheries and the Environment, Fisheries and Marine Service, Freshwater Institute, Winnipeg, Man. R3T 2N6

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The rainbow trout, *Salmo gairdneri*, gonad (RTG-2) cell line was more sensitive to lytic infection by infectious pancreatic necrosis virus (IPNV) than was the fathead minnow, *Pimephales promelas*, (FHM) cell line in laboratory and field studies. Laboratory investigations with known strains of IPNV (VR 299 and Buhl) also indicated that the cytopathic response in IPNV-infected chinook salmon, *Oncorhynchus tshawytscha*, embryo (CHSE-214) cells was greater than in infected FHM cells. In contrast, titration experiments with standard infectious hematopoietic necrosis virus (IHNV) isolates (Oregon and Cedar River) showed that the FHM cells were more sensitive to destructive infection by IHNV than was either of the salmonid cell lines (RTG-2, CHSE-214).

Key words: fish cell culture, infectious pancreatic necrosis virus, infectious hematopoietic necrosis virus, chinook salmon embryo cells, fathead minnow cells, rainbow trout cells, salmonid viruses

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En laboratoire et sur le terrain, le virus à nécroses infectieuses du pancréas (VNIP) a provoqué une cytolyse plus forte chez la lignée de cellules sexuelles (RTG-2) de la truite arc-en-ciel, *Salmo gairdneri*, que chez celle du tête-de-boule, *Pimephales promelas*. Des études de laboratoire avec des souches connues de VNIP (VR 299 et Buhl) ont montré que la cytolyse était aussi plus importante chez les cellules embryonnaires (CHSE-214) du saumon chinook, *Oncorhynchus tshawytscha*, que chez celles du tête-de-boule. En revanche, après inoculation de virus à nécroses infectieuses de l'hémopoièse (VNIH) (isolats Oregon and Cedar River) les dosages ont révélé que les cellules de tête-de-boule avaient été détruites en plus grand nombre que celles de l'un ou l'autre des deux autres lignées de salmonidés (RTG-2, CHSE-214).

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ONLY a few continuous fish cell lines have been widely used for the isolation of salmonid viruses. Currently accepted diagnostic procedures for the detection of trout viruses are dependent upon the production of cytopathic effects (CPE) in fathead minnow, *Pimephales promelas*, (FHM) cell cultures, or rainbow trout, *Salmo gairdneri*, gonad (RTG-2) cell cultures (Gillespie et al. 1974; American Fisheries Society, Fish Health Section 1975). In the present study, standard methodology (Gillespie et al. 1974) was employed to identify infectious pancreatic necrosis virus (IPNV) in salmonids from two hatcheries. As indicated for other North American variants of IPNV (B. L. Nicholson, communication at American Fisheries Society Fish Health Section Workshop, Denver 1976), it became apparent that RTG-2 cells were more sensitive than FHM cells for the isolation. In a controlled laboratory study a further comparison was made of the relative sensitivity of three fish cell lines for the assay of two IPNV strains, VR 299 and Buhl, and for the titration of infectious hematopoietic necrosis virus (IHNV) isolates, Oregon and Cedar River.

Materials and methods — Cell cultures — Certified FHM cells, utilized for IPNV detection and assay, were from the American Type Culture Collection (ATCC, #CCL 42). The chinook salmon, *Oncorhynchus tshawytscha*, embryo (CHSE-214) cell line of Fryer et al. (1965) and the RTG-2 cell line (ATCC, #CCL 55) used for IPNV assay were provided by Dr T. Yamamoto (University of Alberta). The RTG-2 and FHM cells used for IHNV assay were obtained as certified cultures from the American Type Culture Collection. These were utilized within seven in vitro passages of acquisition. Salmonid cells were grown at 20°C, the FHM cells at 20–30°C, in 75-cm^2 plastic flasks in Eagle's minimum

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essential medium supplemented with 10% fetal bovine serum, with added penicillin (100 IU/mL) and streptomycin (100 μg/mL).

Cells, which were inoculated directly with virus or tissue extracts, received the same culture medium described above, but with 2% serum. Cell cultures selected for titration of IHNV were grown once in medium with gentamicin sulfate (100 μg/mL) before the assay. For only one experiment gentamicin sulfate was employed directly in the cell culture medium used for IPNV assay without effect.

Standard virus stocks — The IPNV (VR 299) was provided by Dr R. Sonstegard (University of Guelph) and the Buhl strain of IPNV (Wolf and Quimby 1971) by Dr D. Amend (Tavolek Laboratories, Redmond, Wash.). The Oregon strain (OSV) of IHNV (Wingfield et al. 1970) was provided by Dr T. Yamamoto and a Cedar River isolate (Amend and Wood 1972) by Dr T. P. T. Evelyn (Fisheries and Marine Service, Nanaimo, B.C.). Comparative assays were made on virus stocks prepared from material that had been previously passaged (twice) in RTG-2 cells in this laboratory.

For preparation of IPNV stocks, RTG-2 monolayers were infected at a low multiplicity of infection (MOI $\leq$ 1). Cells were incubated at 20°C until maximum CPE was evident. Cell-fluid harvests were subject to intermittent sonication (20 kilocyles/s) for 1 min to release cell-associated virus (Moss and Gravell 1969). The cellular debris was removed by centrifugation, and the virus was stored at 4°C in 50% glycerol (Wolf et al. 1960).

The RTG-2 cell monolayers that were infected with IHNV (MOI $<$ .01) were held at 15°C until maximum CPE occurred. The pooled culture fluids were frozen-thawed (three times) and clarified by removal of debris by centrifugation. Virus-containing fluids were then stored in small aliquots at −70°C.

Virus titrations — Plaque assay — The viral susceptibility of each cell line was determined by the plaque assay–HEPES (14 mmol/L) buffer two-phase overlay method, using the appropriate seeding densities, incubation times, and temperatures recommended by Wolf and Quimby (1973).

Dilution end-point — Virus was titered by a standard dilution end-point method: the 50% tissue culture infectious dose (TCID50) viral assay procedure, using 4 cultures/dilution. Cultures of FHM, RTG-2, and CHSE-214 cells were grown in plastic tissue culture tubes. Alternatively, cell monolayers for assay of IHNV were prepared in tissue culture cluster plates having 24 wells (16 mm diameter) per plate. Cell cultures were drained, and each received 0.1 mL of a tenfold virus dilution in minimum essential medium. Virus was absorbed for 30 min, then fresh medium was added, and the cultures were incubated at the appropriate temperatures. After 2 wk, titers were calculated by the method of Reed and Muench (1938).

Primary virus isolation — Standard diagnostic procedures, which were modified slightly from Gillespie et al. (1974), were used for virus detection. In each case, replicate drained cell cultures in 24-well tissue culture cluster plates received 0.2 mL of a 2% filtered clarified tissue homogenate prepared from kidneys, spleen, and pyloric ceca–pancreas (volume 3:1:1). After 30 min at 15°C cell cultures were drained and medium was added. After 1 wk at 15°C material was passaged, and the new cultures were incubated for 7 d at 15°C. Definitive CPE occurring in the transfer cultures within 1 wk was recorded as positive. Confirming identification of isolated virus as IPNV was based upon characteristic CPE in RTG-2 cells, common physical properties with strain VR 299, and neutralization by antisera.

Results and discussion — Twelve out of a total of 24 diagnostic samples yielded detectable IPNV in RTG-2 cells. In contrast, only three of the total samples assayed in FHM cells were positive after transfer:

Sample source	Cell lines	
	FHM	RTG-2
Hatchery A	3/12	9/12
Hatchery B	0/12	3/12

Samples that were positive in FHM cells were also positive when assayed in RTG-2 cells.

Further testing showed that the CHSE-214 line was more sensitive than the FHM cell system and at least as sensitive as the RTG-2 cell line for the enumeration of the IPNV (Table 1). Final end-point titers of IPNV were comparable in RTG-2 and CHSE-214 cells, but the IPN virus induced detectable CPE more rapidly in the chinook cells, as previously noted by Yamamoto (1974). Thus, the CHSE-214 cells would appear preferable to either FHM or RTG-2 cells for the detection of IPNV.

Our preparation of the Buhl strain failed to form plaques or to cause readily detectable CPE at any dilution in FHM cells. Whether significant replication had occurred in the absence of detectable CPE was not determined. However, results of other investigators would indicate that this phenomenon is partly attributable to the failure of the IPNV particles to adsorb to the FHM cells (Scherrer and Cohen 1975; B. L. Nicholson, University of Maine, personal communication). Lack of cellular susceptibility to lytic infection probably resides in the virus preparations themselves and not in the cells, since strain VR 299 was capable of causing CPE in these cells.

The FHM cells are apparently more sensitive to IHNV than are either of the other cell lines (Table 2). This observation is in agreement with the observations of Amend et al. (1969) that for primary isolation, FHM cells are generally more sensitive to IHNV-induced CPE than are RTG-2 cells. However, FHM cells and chinook salmon embryo cells under certain conditions may resist isolation of some IHNV strains (Holway and Smith

TABLE 1. A comparison of two assay procedures using strains of IPNV on three fish cell lines — FHM, RTG-2, and CHSE-214, PFU = plaque-forming unit.

IPNV strain[a]	Plaque assay (PFU/mL)			50% end-point (TCID50/mL)		
	FHM	RTG-2	CHSE-214	FHM	RTG-2	CHSE-214
VR 299	1×10^7	7×10^7	6×10^7	3×10^7	5×10^8	6×10^8
Buhl	0[b]	5×10^7	6×10^7	0	3×10^6	3×10^7

[a]A virus stock of each strain of IPNV was prepared in RTG-2 cells. Titers were subsequently assayed in each of the three cell lines (FHM, RTG-2, CHSE-214) using two standard titration procedures, plaque assay (Wolf and Quimby 1973) and dilution end-point.

[b]No plaques at dilutions tested (10^{-1} to 10^{-3}).

TABLE 2. A comparison of two assay procedures using IHNV isolates on three fish cell lines.

IHNV isolate[a]	Plaque assay (PFU/mL)			50% end-point (TCID50/mL)		
	FHM	RTG-2	CHSE-214	FHM	RTG-2	CHSE-214
Cedar River (CR)	5×10^7	8×10^6	5×10^6	3×10^7	3×10^6	1×10^7
Oregon (OSV)	1×10^7	6×10^4	2×10^6	3×10^7	3×10^4	7×10^5

[a]A virus stock of each isolate of IHNV was prepared in RTG-2 cells. Titers were then assayed in each of the three cell lines using two standard titration procedures, plaque assay and dilution end-point.

1973; Wingfield et al. 1970). Furthermore, the CHSE-214 cell line used in our experiments has been effectively employed for the isolation of both IHNV and IPNV in a dual infection (Mulcahy and Fryer 1976). Table 2 shows that CHSE-214 cells should be at least equivalent in sensitivity to RTG-2 cells for the detection of IHNV-induced CPE. Possibly autointerference factors, attributable to the presence of varying amounts of noninfectious particles in salmonid virus preparations (McMichael et al. 1975; McAllister and Pilcher 1974), might influence the end-point titers obtained in different cell systems.

Although a detailed study of cellular properties was not done, we find that the CHSE-214 cells are superior to either of the other two types in terms of general adaptability and overall ease of laboratory manipulation. The FHM cells, which are widely used for growth and detection of fish rhabdoviruses such as IHNV, often have a tendency to slough from growing surfaces, thus limiting their usefulness for diagnostic virology. The use of two cell lines for primary detection of viruses is supported by these observations. However, in North America, where IPNV and IHNV are the predominant salmonid viruses, the CHSE-214 cell line would appear to offer an effective alternative to either of the cell lines currently in common use.

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Ionization of Ammonia in Seawater: Effects of Temperature, pH, and Salinity

CAROL E. BOWER

Sea Research Foundation, Institute for Aquarium Studies, P.O. Box 7-495, West Hartford, Conn. 06107, USA

AND JOSEPH P. BIDWELL

Aquarium Systems, Eastlake, Ohio 44094, USA

BOWER, C. E., AND J. P. BIDWELL. 1978. Ionization of ammonia in seawater: effects of temperature, pH, and salinity. J. Fish. Res. Board Can. 35: 1012–1016.

Previous studies have shown that the toxicity of ammonia to freshwater fishes depends on the ambient concentration of the un-ionized fraction (NH_3) and have quantified the percent NH_3 in solution as a function of temperature and pH. If NH_3 is also toxic to marine fishes, the effect of salinity on the ionization of ammonia must also be considered. The percent NH_3 over ranges of temperature, pH, and salinity common in seawater-culture situations is presented here.

Key words: ammonia, ammonia analysis, ammonia ionization, ammonia toxicity, pH, salinity, temperature

BOWER, C. E., AND J. P. BIDWELL. 1978. Ionization of ammonia in seawater: effects of temperature, pH, and salinity. J. Fish. Res. Board Can. 35: 1012–1016.

La toxicité de l'ammoniac chez les poissons d'eau douce dépend de la concentration ambiante de la fraction non ionisée (NH_3), et des études antérieures ont déterminé le pourcentage de NH_3 en fonction de la température et du pH. Si le NH_3 est aussi toxique chez les poissons marins, il faut considérer aussi l'effet de salinité sur l'ionisation de l'ammoniac. Nous présentons ici les pourcentages de NH_3 dans les intervalles ordinaires de température, de pH et de salinité dans les aquariums marins.

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THE influence of environmental conditions on the toxicity of ammonia to freshwater fishes has been studied extensively (see European Inland Fisheries Advisory Commission 1973, for a comprehensive review). Although the accumulation of ammonia undoubtedly represents a major problem in seawater culture, particularly in recirculating aquariums during the "run-in period," i.e. the preestablishment phase of biological filtration by nitrifying bacteria (Sacki 1958; Kawai et al. 1965; Hirayama 1974), the toxicity of ammonia to marine teleosts apparently has not been studied.

In aqueous solution ammonia is present in two forms, ionized (NH_4^+) and un-ionized (NH_3), represented by the equilibrium equation

$$NH_4^+ + H_2O \rightleftharpoons NH_3 + H_3O^+.$$

NH_3 is regarded as the form of ammonia that is toxic to freshwater fishes (Wuhrmann and Woker 1948; Downing and Merkens 1955) because it is uncharged and lipid soluble, whereas the permeability of plasma membranes to charged, hydrated ammonium ions is relatively low (Jacobs 1940; Milne et al. 1958). The relative proportions of NH_3 and NH_4^+ in solution depend chiefly on temperature and pH and, to a lesser extent, on salinity; concentrations of NH_3 increase with elevated temperatures and pH values and decrease with higher salinities. If NH_3 is the toxic ammonia species in seawater, it is important to know how its concentration is influenced by variations of these conditions.

Values for total ammonia ($NH_3 + NH_4^+$) in natural waters can be determined analytically by several methods (e.g. Grasshoff and Johannsen 1972; Gilbert and Clay 1973; Beckett and Wilson 1974; Hampson 1977a),

TABLE 1. Mean values for pK_a^s in seawater at 25°C and 1 atm pressure, assuming $pK_a^0 = 9.245$ (Bates and Pinching 1949). (Adapted from Whitfield 1974.)

Molal ionic strength	Salinity (‰)	pK_a^s
0.4	18–22	9.29±0.02
0.5	23–27	9.32±0.02
0.6	28–31	9.33±0.02
0.7	32–36	9.35±0.02
0.8	37–40	9.35±0.02

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TABLE 2. Percent un-ionized ammonia in seawater (S = 18–22‰) at different temperatures and pH's.

Temp (°C)	pK_a^s	pH										
		7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5
0	10.10	0.251	0.315	0.397	0.499	0.627	0.788	0.990	1.24	1.56	1.96	2.45
1	10.07	0.270	0.340	0.427	0.537	0.675	0.849	1.07	1.34	1.68	2.11	2.64
2	10.04	0.291	0.366	0.460	0.578	0.727	0.914	1.15	1.44	1.81	2.26	2.83
3	10.00	0.313	0.394	0.495	0.623	0.783	0.984	1.24	1.55	1.94	2.44	3.05
4	9.97	0.337	0.424	0.534	0.671	0.843	1.06	1.33	1.67	2.09	2.62	3.27
5	9.94	0.363	0.457	0.575	0.723	0.908	1.14	1.43	1.80	2.25	2.82	3.52
6	9.91	0.391	0.492	0.619	0.778	0.978	1.23	1.54	1.93	2.42	3.03	3.78
7	9.87	0.422	0.530	0.667	0.838	1.05	1.32	1.66	2.08	2.60	3.25	4.06
8	9.84	0.454	0.571	0.718	0.902	1.13	1.42	1.78	2.24	2.80	3.50	4.36
9	9.81	0.489	0.615	0.773	0.971	1.22	1.53	1.92	2.41	3.01	3.76	4.69
10	9.78	0.527	0.662	0.832	1.05	1.31	1.65	2.07	2.59	3.23	4.04	5.03
11	9.74	0.567	0.713	0.896	1.13	1.41	1.77	2.22	2.78	3.48	4.34	5.40
12	9.71	0.611	0.768	0.965	1.21	1.52	1.91	2.39	2.99	3.74	4.66	5.79
13	9.68	0.658	0.827	1.04	1.31	1.64	2.05	2.57	3.21	4.01	5.00	6.21
14	9.65	0.709	0.891	1.12	1.40	1.76	2.21	2.76	3.45	4.31	5.37	6.66
15	9.61	0.763	0.959	1.20	1.51	1.90	2.37	2.97	3.71	4.63	5.76	7.14
16	9.58	0.822	1.03	1.30	1.63	2.04	2.55	3.19	3.99	4.97	6.18	7.65
17	9.55	0.885	1.11	1.40	1.75	2.19	2.75	3.43	4.28	5.33	6.62	8.20
18	9.52	0.953	1.20	1.50	1.88	2.36	2.95	3.69	4.60	5.72	7.10	8.78
19	9.48	1.03	1.29	1.62	2.03	2.54	3.17	3.96	4.94	6.14	7.61	9.39
20	9.45	1.11	1.39	1.74	2.18	2.73	3.41	4.26	5.30	6.58	8.15	10.0
21	9.42	1.19	1.49	1.87	2.35	2.93	3.67	4.57	5.69	7.06	8.73	10.7
22	9.39	1.28	1.61	2.01	2.52	3.15	3.94	4.91	6.10	7.56	9.34	11.5
23	9.35	1.38	1.73	2.17	2.71	3.39	4.23	5.27	6.54	8.10	9.99	12.3
24	9.32	1.48	1.86	2.33	2.92	3.64	4.54	5.65	7.02	8.67	10.7	13.1
25	9.29	1.60	2.00	2.51	3.14	3.91	4.88	6.07	7.52	9.28	11.4	14.0

TABLE 3. Percent un-ionized ammonia in seawater (S = 23–27‰) at different temperatures and pH's.

Temp (°C)	pK_a^s	pH										
		7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5
0	10.13	0.234	0.294	0.370	0.466	0.585	0.736	0.925	1.16	1.46	1.83	2.29
1	10.10	0.252	0.317	0.399	0.501	0.630	0.792	0.996	1.25	1.57	1.97	2.46
2	10.07	0.271	0.341	0.429	0.540	0.679	0.853	1.07	1.35	1.69	2.12	2.65
3	10.03	0.292	0.368	0.463	0.582	0.731	0.919	1.15	1.45	1.82	2.28	2.85
4	10.00	0.315	0.396	0.498	0.626	0.787	0.989	1.24	1.56	1.95	2.45	3.06
5	9.97	0.339	0.427	0.537	0.675	0.848	1.07	1.34	1.68	2.10	2.63	3.29
6	9.94	0.365	0.460	0.578	0.726	0.913	1.15	1.44	1.81	2.26	2.83	3.54
7	9.90	0.394	0.495	0.622	0.782	0.983	1.23	1.55	1.94	2.43	3.04	3.80
8	9.87	0.424	0.533	0.670	0.842	1.06	1.33	1.67	2.09	2.62	3.27	4.08
9	9.84	0.457	0.574	0.722	0.907	1.14	1.43	1.79	2.25	2.81	3.52	4.39
10	9.81	0.492	0.618	0.777	0.977	1.23	1.54	1.93	2.42	3.03	3.78	4.71
11	9.77	0.530	0.666	0.837	1.05	1.32	1.66	2.08	2.60	3.25	4.06	5.06
12	9.74	0.571	0.717	0.901	1.13	1.42	1.78	2.23	2.80	3.49	4.36	5.43
13	9.71	0.615	0.772	0.970	1.22	1.53	1.92	2.40	3.01	3.76	4.68	5.82
14	9.68	0.662	0.832	1.05	1.31	1.65	2.06	2.58	3.23	4.03	5.03	6.25
15	9.64	0.713	0.896	1.13	1.41	1.77	2.22	2.78	3.47	4.33	5.39	6.70
16	9.61	0.767	0.964	1.21	1.52	1.91	2.39	2.99	3.73	4.65	5.79	7.18
17	9.58	0.826	1.04	1.30	1.64	2.05	2.57	3.21	4.01	5.00	6.21	7.69
18	9.55	0.890	1.12	1.40	1.76	2.21	2.76	3.45	4.31	5.36	6.66	8.24
19	9.51	0.958	1.20	1.51	1.89	2.37	2.97	3.71	4.62	5.75	7.14	8.82
20	9.48	1.03	1.30	1.63	2.04	2.55	3.19	3.98	4.97	6.17	7.65	9.44
21	9.45	1.11	1.39	1.75	2.19	2.74	3.43	4.28	5.33	6.62	8.19	10.1
22	9.42	1.20	1.50	1.88	2.36	2.95	3.69	4.60	5.72	7.09	8.77	10.8
23	9.38	1.29	1.62	2.03	2.54	3.17	3.96	4.93	6.13	7.60	9.38	11.5
24	9.35	1.39	1.74	2.18	2.73	3.41	4.25	5.30	6.58	8.14	10.0	12.3
25	9.32	1.49	1.87	2.34	2.93	3.66	4.57	5.68	7.05	8.72	10.7	13.1

TABLE 4. Percent un-ionized ammonia in seawater (S = 28–31‰) at different temperatures and pH's.

Temp (°C)	pK_a^s	pH										
		7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5
0	10.14	0.229	0.288	0.362	0.455	0.572	0.719	0.904	1.14	1.43	1.79	2.24
1	10.11	0.246	0.310	0.390	0.490	0.616	0.775	0.973	1.22	1.53	1.92	2.41
2	10.08	0.265	0.334	0.420	0.528	0.664	0.834	1.05	1.32	1.65	2.07	2.59
3	10.04	0.286	0.359	0.452	0.568	0.715	0.898	1.13	1.42	1.78	2.23	2.79
4	10.01	0.308	0.387	0.487	0.612	0.770	0.967	1.21	1.52	1.91	2.39	3.00
5	9.98	0.332	0.417	0.524	0.659	0.829	1.04	1.31	1.64	2.06	2.57	3.22
6	9.95	0.357	0.449	0.565	0.710	0.892	1.12	1.41	1.77	2.21	2.77	3.46
7	9.91	0.385	0.484	0.608	0.765	0.961	1.21	1.51	1.90	2.38	2.98	3.72
8	9.88	0.414	0.521	0.655	0.823	1.03	1.30	1.63	2.04	2.56	3.20	4.00
9	9.85	0.446	0.561	0.706	0.887	1.11	1.40	1.75	2.20	2.75	3.44	4.29
10	9.82	0.481	0.604	0.760	0.955	1.20	1.51	1.89	2.36	2.96	3.70	4.61
11	9.78	0.518	0.651	0.818	1.03	1.29	1.62	2.03	2.54	3.18	3.97	4.95
12	9.75	0.558	0.701	0.881	1.11	1.39	1.74	2.18	2.73	3.42	4.27	5.31
13	9.72	0.601	0.755	0.949	1.19	1.50	1.88	2.35	2.94	3.67	4.58	5.70
14	9.69	0.647	0.813	1.02	1.28	1.61	2.02	2.53	3.16	3.95	4.92	6.11
15	9.65	0.697	0.875	1.10	1.38	1.73	2.17	2.72	3.40	4.24	5.28	6.56
16	9.62	0.750	0.943	1.18	1.49	1.86	2.33	2.92	3.65	4.55	5.66	7.03
17	9.59	0.808	1.02	1.27	1.60	2.01	2.51	3.14	3.92	4.89	6.08	7.53
18	9.56	0.870	1.06	1.37	1.72	2.16	2.70	3.38	4.21	5.25	6.52	8.07
19	9.52	0.937	1.18	1.48	1.85	2.32	2.90	3.63	4.52	5.63	6.99	8.64
20	9.49	1.01	1.27	1.59	1.99	2.50	3.12	3.90	4.86	6.04	7.49	9.24
21	9.46	1.09	1.36	1.71	2.14	2.68	3.35	4.19	5.21	6.48	8.02	9.89
22	9.43	1.17	1.47	1.84	2.31	2.89	3.61	4.50	5.60	6.94	8.59	10.6
23	9.39	1.26	1.58	1.98	2.48	3.10	3.87	4.83	6.00	7.44	9.19	11.3
24	9.36	1.35	1.70	2.13	2.67	3.33	4.16	5.18	6.44	7.97	9.83	12.1
25	9.33	1.46	1.83	2.29	2.87	3.58	4.47	5.56	6.90	8.54	10.5	12.9

TABLE 5. Percent un-ionized ammonia in seawater (S = 32–40‰) at different temperatures and pH's.

Temp (°C)	pK_a^s	pH										
		7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	8.5
0	10.16	0.218	0.275	0.346	0.435	0.547	0.687	0.863	1.09	1.36	1.71	2.14
1	10.13	0.235	0.296	0.372	0.468	0.589	0.740	0.930	1.17	1.47	1.84	2.30
2	10.10	0.253	0.319	0.401	0.504	0.634	0.797	1.00	1.26	1.58	1.98	2.48
3	10.06	0.273	0.343	0.432	0.543	0.683	0.858	1.08	1.35	1.70	2.13	2.66
4	10.03	0.294	0.370	0.465	0.585	0.735	0.924	1.16	1.46	1.83	2.29	2.86
5	10.00	0.317	0.398	0.501	0.630	0.792	0.995	1.25	1.57	1.97	2.46	3.08
6	9.97	0.341	0.429	0.540	0.678	0.852	1.07	1.34	1.69	2.11	2.65	3.31
7	9.93	0.367	0.462	0.581	0.730	0.918	1.15	1.45	1.82	2.27	2.85	3.56
8	9.90	0.396	0.498	0.626	0.787	0.988	1.24	1.56	1.95	2.45	3.06	3.82
9	9.87	0.426	0.536	0.674	0.847	1.06	1.34	1.68	2.10	2.63	3.29	4.11
10	9.84	0.459	0.577	0.726	0.912	1.15	1.44	1.80	2.26	2.83	3.54	4.41
11	9.80	0.495	0.622	0.782	0.982	1.23	1.55	1.94	2.43	3.04	3.80	4.74
12	9.77	0.533	0.670	0.842	1.06	1.33	1.67	2.09	2.61	3.27	4.08	5.08
13	9.74	0.574	0.721	0.906	1.14	1.43	1.79	2.25	2.81	3.51	4.38	5.46
14	9.71	0.618	0.777	0.976	1.23	1.54	1.93	2.42	3.02	3.78	4.71	5.85
15	9.67	0.665	0.836	1.05	1.32	1.66	2.07	2.60	3.25	4.06	5.05	6.28
16	9.64	0.717	0.900	1.13	1.42	1.78	2.23	2.79	3.49	4.36	5.42	6.73
17	9.61	0.772	0.970	1.22	1.53	1.92	2.40	3.00	3.75	4.68	5.82	7.22
18	9.58	0.831	1.04	1.31	1.64	2.06	2.58	3.23	4.03	5.02	6.24	7.73
19	9.54	0.895	1.12	1.41	1.77	2.22	2.78	3.47	4.33	5.39	6.69	8.28
20	9.51	0.963	1.21	1.52	1.90	2.39	2.98	3.73	4.65	5.78	7.17	8.87
21	9.48	1.04	1.30	1.63	2.05	2.57	3.21	4.01	4.99	6.20	7.69	9.49
22	9.45	1.12	1.40	1.76	2.20	2.76	3.45	4.30	5.36	6.65	8.23	10.1
23	9.41	1.20	1.51	1.89	2.37	2.97	3.71	4.62	5.75	7.13	8.81	10.8
24	9.38	1.29	1.62	2.04	2.55	3.19	3.98	4.96	6.17	7.64	9.43	11.6
25	9.35	1.39	1.75	2.19	2.74	3.43	4.28	5.32	6.61	8.18	10.1	12.4

but there is no direct way to assess the concentration of un-ionized ammonia. The percent un-ionized ammonia in freshwater is calculated, usually from the value obtained for total ammonia, by using the equation

$$\% \text{ un-ionized Ammonia} = 100/[1 + \text{antilog}\,(pK_a^{\circ} - pH)],$$

where pK_a^0 is the negative logarithm of the ionization constant at zero salinity. Values for the percent un-ionized ammonia in freshwater at different temperatures and pH values have been tabulated by Trussell (1972) and Emerson et al. (1975). Because of the effect of salinity on the ammonia–water equilibrium, however, these tables are not reliable for estimations in seawater. Skarheim (1973) prepared tables in which the effect of salinities up to 35‰ was taken into consideration, but according to Emerson et al. (1975) his reported equilibrium constants were based on "questionable assumptions," and his method of calculation was not made clear.

Using several different ionic interaction models, Whitfield (1974) calculated the effects of ionic strength, temperature, and pressure on the hydrolysis of ammonium ions. The tables presented in this paper follow Whitfield's recommendation that the overall mean values for his models at 1 atm pressure, 25°C, and different ionic strengths (Table 1) be considered as representative of the overall acid hydrolysis constants of ammonium ions in seawater ($= pK_a^s$). Hampson (1977b) described a computer program, based on Whitfield's data, for calculating the concentration of NH_3 in natural waters, but for reasons unknown to us, his pK_a^s values were different from those recommended by Whitfield.

Salinities (*S*‰) corresponding to the molal ionic strength (*I*) of seawater were calculated from the equation (Whitfield 1974)

$$I = 19.9273\, S‰/(100 - 1.005109\, S‰).$$

The percent un-ionized ammonia at different temperatures, pH values, and salinities (Tables 2–5) was calculated from the following equation derived from Whitfield's calculations:

$$\% \text{ un-ionized Ammonia} = 100/[1 + \text{antilog}\,(pK_a^s(T) - pH)],$$

in which

$$pK_a^s(T) = pK_a^s(T = 298°K) + 0.0324(298 - T°K).$$

The pH range used in the present study includes the upper and lower extremes found in natural ocean waters (Sverdrup et al. 1942) and is thus considerably more narrow than that intended for application in freshwater.

By using Tables 2–5, the concentration of NH_3 in seawater at temperatures from 0 to 25°C, pH's from 7.5 to 8.5, and salinities from 18 to 40‰ can be estimated from values for total ammonia obtained by conventional analytical methods. Values for the percent NH_3 at the lowest salinity studied are virtually the same as values given for freshwater by Emerson et al. (1975), especially at lower temperatures; but at salinities common in seawater culture (32–40‰) there is up to one-fifth less un-ionized ammonia than in freshwater at the same temperature and pH.

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PERSPECTIVES

Management Alternatives and Strategic Planning for Canada's Fisheries

WILLIAM F. SINCLAIR

Department of Fisheries and the Environment, Fisheries and Marine Service, Economic Services, Ontario Region

Contents

ABSTRACT/RÉSUMÉ 1017
INTRODUCTION 1018
FISHERIES MANAGEMENT FOR PUBLIC BENEFIT 1019
OPEN-ACCESS FISHERIES 1019
STRATEGIC PLANNING FOR CANADA'S FISHERIES 1020
FISHERIES MANAGEMENT ALTERNATIVES 1024
RECOMMENDED MANAGEMENT SYSTEM FOR CANADA'S FISHERIES 1026
SPORT FISHERIES 1028
OTHER RELATED ISSUES 1028
ACKNOWLEDGMENTS 1028
REFERENCES 1029
ADDITIONAL REFERENCES 1029

Abstract

SINCLAIR, W. F. 1978. Management alternatives and strategic planning for Canada's fisheries. J. Fish. Res. Board Can. 35: 1017–1030.

The evils of operating Canada's commercial and recreational fisheries under open-access conditions were known before Confederation. Early recognition of these ills did not lead to an understanding of the basic problems nor to long-term solutions. In the early 1950s the first economic model was developed that articulated the underlying causes of excess capacity and the tendency of overexploitation in open-access fisheries. This was followed by a number of studies that explored the relationship between the biological reproductive capacity of a fishery and the economic consequences of managing publicly owned resources under open-access conditions. This early work provides a general framework from which a number of fisheries management alternatives emerge. Each of six management alternatives, which are implicit in policy for Canada's commercial fisheries, are assessed in terms of political acceptability, administrative feasibility, and effectiveness. It is emphasized that the responsibility of a government fisheries agency is to manage fisheries resources in the best interest of the owners of the resource – the nation's taxpayers. A properly implemented license control system would dissipate, rather than perpetuate, social and economic hardship among fishermen. This misplaced concern for unproven social problems often leads fisheries managers to support programs that sacrifice all the benefits that could be generated from the resource and the resource itself. A management scheme is recommended that encompasses a simple licensing system, a tax or a royalty on catch, and a limited variation of the "Grandfather System." The combination of these three incorporates the main advantages of most management alternatives while avoiding most of their main shortcomings. A carefully implemented program that accounts for economic and biological considerations would improve the efficiency of the industry, improve fishermen's incomes, minimize social disruptions, help to instill an environmental conscience, protect the resource, and induce less, rather than more, government intervention into the free operation of the fishing industry. Probably more important, the program would generate an economic return for the people of Canada.

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Résumé

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On avait réalisé, bien avant la Confédération, les inconvénients que comportait l'accès libre aux pêches commerciales et récréatives du Canada. Néanmoins, cette réalisation n'a pas conduit à la compréhension des problèmes fondamentaux non plus qu'aux solutions à long terme. C'est au début des années 1950 qu'on a construit le premier modèle économique définissant les facteurs responsables de la surcapitalisation et de la tendance vers la surexploitation que l'on trouve dans les pêcheries où l'accès est libre. Vinrent ensuite plusieurs études portant sur la relation entre la capacité biologique de reproduction d'une pêcherie et les conséquences économiques de la gestion de ressources de propriété publique dans des conditions d'accès libre. Ces travaux du début servent de cadre général à partir duquel émergent plusieurs options de gestion des pêches. L'auteur évalue ces options, implicites dans la politique canadienne des pêches commerciales, sous les aspects suivants : sont-elles acceptables du point de vue politique, sont-elles pratiques au point de vue administratif et sont-elles efficaces. Il souligne qu'un organisme gouvernemental chargé des pêches a comme responsabilité de gérer les ressources halieutiques dans le meilleur intérêt des propriétaires — les contribuables du pays. Un système de contrôle des permis bien administré aurait pour effet d'éliminer, plutôt que de perpétuer, les difficultés sociales et économiques des pêcheurs. Cet intérêt mal placé pour des problèmes sociaux qui ne sont pas prouvés porte souvent les gestionnaires des pêches à appuyer des programmes qui détruisent tous les bénéfices que pourrait engendrer la ressource, et la ressource elle-même. L'auteur recommande un plan de gestion englobant un système simple de permis, une taxe ou royauté sur les captures et une variante limitée du « système des droits acquis ». Ces trois facteurs combinés offrent les principaux avantages de la plupart des options de gestion tout en évitant leurs principaux inconvénients. Un programme appliqué avec soin et qui tient compte de considérations économiques et biologiques aurait pour résultat d'améliorer l'efficacité de l'industrie, de relever le niveau de gains des pêcheurs, de minimiser les perturbations sociales, d'inciter les gens à protéger l'environnement et la ressource, et de diminuer, plutôt que d'augmenter, l'intervention gouvernementale dans le libre fonctionnement de l'industrie des pêches. Plus important encore, le programme engendrerait des profits pour les Canadiens.

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Introduction

Stock depletion, overcapitalization, and low income levels have been prominent features in Canada's commercial fisheries since before Confederation. Early annual reports by the superintendents of fisheries for the various regions in Canada often made reference to the needs for greater protection of the fisheries resource. They contain many passages that outlined the evils of operating Canada's commercial and recreational fisheries under open-access conditions and urged the adoption of legislation that would limit the privilege of fishing for the common good. These reports contain many recommendations for the adoption of legislation that would help protect the resource, enhance its productive value, and at the same time provide a return to the public treasury. For example, Anon. (1859, p. 85) stated:

> Indiscriminate free fishing here is productive of many social evils — it destroys also the valuable fisheries — and of positive hardships it produces a plentiful crop.

Perhaps of even greater interest in light of today's problems however, is that these reports contain many passages that caution against the use of ill-conceived short-term measures in favor of a system that will ensure the long-term health of Canada's fisheries (Anon 1874).

The early recognition of the problems that prevail in Canada's, and indeed the world's, commercial fisheries did not however, lead to an understanding of the basic problems nor to long-term solutions. The late part of the 1800s and the first half of the 1900s was a period of tremendous improvement in the exploitive capability of commercial fishing fleets and in the understanding of the biological nature of the fisheries resources. Yet it was not until 1953 that an economic model was formulated that articulated the underlying causes of excess capacity and of overexploitation in open-access fisheries (Gordon 1953). This was followed by a number of studies that explored the relationship between the biological reproductive capacity of a fishery and the economic consequences of managing a publicly owned resource under open-access conditions (Crutchfield and Zellner 1961; Turvy 1964; Crutchfield and Pontecorvo

1969). All of this early work provides a general framework from which a number of fisheries management alternatives emerge.

This paper is used to identify and assess these management alternatives in light of the management strategies that Canada can pursue for its fisheries. The first part of the paper briefly reviews the problems encountered in open-access commercial fisheries. Since government strategies can be evaluated only in terms of the purposes they are meant to serve, the second part of the paper is devoted to a general interpretation of the objectives implied in the *Policy for Canada's Commercial Fisheries* (Anon. 1976). The remainder is used to analyze the economic and social implications of each of the various managerial alternatives that are implied in the report. It is intended that this presentation emphasize the complementarity between the fisheries biologists' concern for the resource and the approach advocated by resource economists.

Fisheries Management for Public Benefit

While it is generally understood that the adoption of particular management strategies and the regulations necessary to implement these strategies involve issues of economic efficiency, it is not always understood that they also involve the redistribution of benefits among members of society. Public interest demands that those responsible for managing publicly owned fisheries resources give careful consideration to the effects that fisheries management decisions have on the general public. For example, among the many things affected by fisheries management decisions are the price of fish in the marketplace, the distribution of income, and who will be employed in the fisheries. Economic analysis cannot prescribe issues of fairness or moral correctness. Nonetheless, it can and does provide a framework for analyzing the implications of pursuing particular noneconomic objectives and does shed some light on the effectiveness of particular strategies or policies in achieving these objectives.

In this vein, it is important for those government agencies responsible for managing publicly owned fisheries resources to recognize that concern for the primary users (commercial and recreational fishermen) should *not* be used as justification for establishing programs that may not be in the best public interest. This is not merely a matter of agency responsibility, but a practical consideration that has considerable influence on the political, and consequently, the financial support that resource agencies will continue to receive in future. Canadian taxpayers not only own Canada's fisheries resources but they pay the cost of maintaining these resources for the benefit of existing and future generations. They cannot, however, be expected to support programs that implicitly or explicitly sacrifice the resource and the benefits the general public receives from the resource to provide welfare for a select segment of society. This is not to suggest that short-term programs designed to assist fishermen during periods of economic hardship do not serve the public interest, but rather to emphasize that the primary function of a fisheries resource agency is to manage the fisheries for the general public good and not to assume the responsibilities of Health and Welfare, Manpower and Immigration, Department of Regional Economic Expansion, and other such agencies.

It should also be recognized that any management system that eliminates the tendency to dissipate the net value of the fisheries resource because of overcapitalization will generate benefits. Those responsible for managing fisheries will have the potential to influence those who eventually realize these benefits. The fishermen can be expected to advocate those decisions that would favor their position, just as the fishing industry will favor those measures that will allow them to capture additional benefits in the form of increased profit. It is important that fisheries administrators ensure that taxpayers, as owners of the resource, receive an adequate share of these benefits. Presumably, these gains could be funneled into the public treasury, but precisely how the return would be divided between the two senior levels of government is a political issue that should be given careful consideration in future.

Open-Access Fisheries

A considerable amount has been written about the economic waste generated when fisheries are managed under open-access conditions (Gordon 1953; Sinclair 1960; Christy and Scott 1965; Crutchfield and Pontecorvo 1969). Most of this literature, however, stresses the competitive aspects of fishing under these conditions. The standard model shows that when everyone who wants to fish can fish, there is a tendency to dissipate economic rent (defined as a residual payment to the resource after labor and capital have been paid) through the creation of excess capacity. More and more manpower and equipment is committed to catching the same fish stocks. Under these conditions the average fisherman, depending on his ability to gain alternative employment, will earn less fishing than he would in other occupations requiring similar skills. The standard solution advocated has been to restrict entry through licence limitation. What is not generally understood, however, is that restricting entry does not in itself eliminate the tendency to overcapitalize or to dissipate economic rents (Bell 1970; Campbell 1973; Keene 1973; Sturman 1976; Anderson 1977). Furthermore, it is not generally understood that overcapitalization is not only economically wasteful but it is wasteful of the resource itself, and can lead to overexploitation of the resource.

Aside from the lack of emphasis on this aspect of overcapitalization in the literature, there are numerous other reasons why the relationship between overcapitalization and the maintenance of a healthy fishery is not fully appreciated. It is worth emphasizing here

that both the stocks that are fished commercially and the commercial fishermen themselves are particularly vulnerable to market conditions. Fishermen's incomes may rise and fall in the short run but they usually decline to low levels under conditions of open access. The same can be said about the welfare of the commercial fishing stocks. New men and equipment will enter an open fishery in response to higher fish prices in the marketplace; effort will rise and the overall harvest is likely to surpass the reproductive capacity of the resource. There are no offsetting influences during periods when market fish prices are declining. The capital equipment necessary to participate in commercial fishing has very little alternative use value; thus fishermen (often lacking alternative employment opportunities) will not leave the fishery and effort and harvest will not decline in the absence of fishing restrictions.

The maintenance of open-access fisheries and the establishment of programs to maintain fishermen in overcapitalized fisheries help to generate and perpetuate poverty and other social ills. Most fisheries regulations are aimed directly at influencing the size, age distributions, and the amount of fish caught. In an overcapitalized fishery, characterized by too many fishermen and too much equipment chasing too few fish, these regulations are likely to have dire economic and social implications. Furthermore, programs adopted to offset temporary disruptions in fishing income merely serve to ensure the continued existence of these basic problems in the long run. Overcapitalization will encourage further overexploitation and the continued dissipation of the resource. This makes it necessary to establish further fishing restrictions, which in turn, causes further social disruption. Subsidies or other short-term measures that do not encourage fishermen to seek other types of employment, nor discourage them from investing in an economically unhealthy fishery, perpetuate social and economic deprivation and hasten the dissipation of the resource. Those who suggest that license-limitation programs cause a disproportionate amount of economic and social hardship should be required to demonstrate that a properly implemented program (which takes place over time and permits social adjustment) is more socially disruptive than the maintenance of an unhealthy fishery.

Strategic Planning for Canada's Fisheries

If commercial fisheries were managed solely in terms of achieving a single set of consistent goals, then it would be a comparatively simple task indeed. However, modern fisheries management is a complex business which practically always entails foregoing benefits in one area to achieve results in others. Economic efficiency is often sacrificed in the interest of protecting fish stocks; fisheries stocks are sometimes subjected to overexploitation to ensure adequate incomes for fishermen and fishing incomes are frequently sacrificed to protect fisheries stocks. Unfortunately, most fisheries management decisions that affect the benefits sacrificed in one area to achieve results in another are made on an *ad hoc* basis. Since the effectiveness of any decisions involving public intervention in the exploitation of fisheries resources can be judged only in light of the areas of concern they are meant to serve, a basic understanding of these concerns and their interrelationships is necessary before a rational management system can be established.

In this regard, six main areas of concern were identified in the *Policy for Canada's Commercial Fisheries* (Anon. 1976). These are

1. conservation and augmentation of Canada's fisheries resources;
2. maintenance of commercial fishing incomes;
3. maintenance of fisheries-related employment opportunities;
4. minimization of social and economic disruptions;
5. creation of public awareness about the importance of maintaining healthy fish communities and ecosystems;
6. attainment of economic efficiency in fish harvesting (Pearse 1971).

Each of these concerns will be discussed in turn.

Conservation and Augmentation of Canada's Fisheries Resources

Almost everyone would agree that there is an overriding need to protect the world's resources from overexploitation and waste. This is particularly true of fisheries resources where overfishing, the destruction of a habitat, and the susceptibility of most fish species to industrial pollution pose a very real and distinct threat to practically all of the world's fish populations. As a result, it has become part of modern man's conventional wisdom to believe that the conservation of fish populations is necessarily good. Very little thought is given to the fact that the term conservation has a variety of meanings and each would engender a different behavior towards the resource.

The definition normally applied by economists is that the world's resources should be protected and managed to obtain a maximum present value of benefits to mankind through time. Of the many definitions applied to the term conservation, this is the only one that is not so narrow that it eliminates the notion of change and of the requirement to provide for man's needs (Barnett 1965; Herfindahl 1965). Indeed, once it is understood that the development of capital utilizes nature's resources and that labor is in itself a scarce resource, the term conservation should encompass a concern for avoiding the wasteful use of labor and capital. This is also consistent with the position taken by biologists who argue the need to protect fisheries resources on a sustained basis. At least in theory, the economist's and biologist's use of the term is not different. Both would argue that the fisheries resources should be managed in

a fashion that ensures that mankind continues to benefit from the fisheries resources over time. Once the compatibility of the economist's and the biologist's understanding toward the resource management is recognized, then an agreement on an appropriate fisheries management system should readily follow.

In practice, however, the compatibility of the economist's and the biologist's approach is less apparent. For example, it is generally recognized that the overexploitation of fish stocks can contribute considerably to the dissipation of fisheries resources and that public control of fish harvest is necessary for the orderly management of these resources. Such controls usually involve either gear restrictions, area closures, or quotas. From an economic perspective, these restrictions raise production costs and detract from the efficiency of the fleet and the individual fisherman. More labor and capital are employed in fishing than existing technology requires and the economy as a whole sacrifices the production of other goods and services.

Those directly involved in fisheries management often argue that gear restrictions are necessary for the protection of the resource. However, such restrictions do not necessarily curtail fishing effort nor do they ensure the protection of the fisheries resources except in the short run; in the long run they simply inhibit or prohibit economic efficiency. Fishermen will respond to such restrictions by increasing their investment in labor and capital. This will continue until all fishermen are satisfied that their economic returns cannot be improved through increased investment. In other words, such restrictions will not necessarily protect the fisheries resources in the long run nor further any socially desirable objectives except possibly the short-term expansion of employment in the fishing industry.

Closures and quotas, which usually are adopted as an administratively simple means of reducing excessive fishing on overfished or threatened stocks, also have a limited beneficial effect. The imposition of area closures almost certainly will discourage commercial fishermen from harvesting threatened stocks in the short run. However, it will also induce commercial fishermen to adjust to the controls so that short-run gains are rapidly eroded. For the individual fishing enterprise, there is a powerful inducement to expand their storage capacity and speed in order to take advantage of the shorter fishing season. The same applies to quotas since the individual fisherman will attempt to lower his costs by continually increasing the speed with which he catches his quota. As the fleet adjusts to these changes, the fishing season will have to be constantly shortened by fisheries managers to offset improvements in the fleet's ability to increase their catch during shorter periods. As this occurs, the cost of handling, storage, and processing will increase and the quality of fish harvest is likely to deteriorate. The cost of marketing fish during short periods will rise and a higher percentage of processed fish (rather than fresh fish) will find its way to the marketplace.

The overall effect of gear restrictions, area closures, and quotas may conserve the fisheries resources in the short run but they do not protect the resources in the long run nor do they improve the economic performance of the fishing industry. They contribute to economic waste and almost certainly reduce the incomes of fishermen in the short run and the long run. This is not to suggest that gear restrictions, area closures, and quotas are not to be used under any circumstances. Quite the contrary, gear restrictions are important for harvest selectivity or maybe even to avoid conflicts among different gear users on the fishing grounds. The intention here is to emphasize that these types of regulations should be kept to an absolute minimum and used as part of a larger management scheme.

There also is considerable dichotomy between the biologist and the resource economist in their attitude towards fish enhancement or the augmentation of the resource. This seems to stem partly from a difference in the attitude towards the application of conserving fish populations, but it is also partly due to the difference in their respective roles. Many biologists advocate the production and enhancement of fish stocks regardless of the amount of benefits that might have to be foregone in other areas. This is not true of the economist who would argue the need to conserve all of nature's resources including labor and capital. Artificial enhancement or aquaculture production offers a broad range of opportunities to supplement nature's ability to produce healthy fish stocks. Nonetheless, all such efforts should be subjected to careful economic and biological scrutiny. They should be entered into only when it is decided that the cost of resources diverted from other government-supported programs is more than covered by the benefits that would accrue to Canadian taxpayers. This requires more than just an agreement that there is a need for economic expediency, but also the need to recognize the inherent dangers in overindulging in one resource area without recognizing the urgency of maintaining other resources.

Conservation and enhancement of Canada's fish populations are important. However, their importance lies not only in man's obligation to nature but in the resource's contribution to the welfare of mankind. Given the foregoing qualifications, the conservation and enhancement of Canada's fisheries resources are consistent with managing a healthy and economically efficient commercial fishing industry.

Maintenance of Commercial Fishing Incomes

Government officials have long recognized the influence that fishing restrictions have on fishermen's earnings. This recognition, together with the seasonal nature of the fishing business and the uncertainties and risks created by sudden changes in regulations, has resulted in the adoption of a number of assistance programs designed to protect and supplement fishing incomes. In Canada, loan arrangements, tax concessions, and unemployment insurance have been used for this purpose.

However, the widespread acceptance of these programs has served to obscure a number of very important factors that should be taken into account when income is included as an element worth pursuing as part of society's goals for fisheries. Firstly, it is extremely difficult to determine what is a reasonable level of fishing income. Aside from the fact that there are practically always wide differences among the earnings of fishermen, fishing income is often used to supplement incomes earned from other sources. What the fisherman expects to earn, and what he may try to influence the fisheries manager to believe is a reasonable income, varies with the level of the fisherman's investment and the level of income he might command in other employment. Further, many fishermen enjoy fishing as a way of life and are perfectly willing to remain fishermen even at lower incomes than they could otherwise earn. This problem is complicated by the fact that, in those situations where a fisherman's earnings might be considered low, there is no way of assessing personal initiative to determine whether the earnings are justified given the amount of effort expended.

The maintenance of commercial fishing income is an element worth pursuing when attempting to conserve and augment the nation's and the provinces' commercial fisheries. It is important to understand that this concern for fishing income should be directed at individual fishermen and not at the fleet as a whole. It is possible to increase the total earned in a commercial fishery at the sacrifice of the resource in the short term. Fisheries managers merely have to permit an ever increasing fishing fleet to catch more and more fish. Even if the price of fish declines, incomes and employment may be maintained by harvesting larger portions of existing stocks. However, it is readily apparent that such behavior would soon lead to destruction of the resource and eliminate the possibility of the fishery generating incomes in the future. It follows, therefore, that the only income related goal worth pursuing is to increase the earnings of individual fishermen. Once again, the fisheries manager can contribute to this by maintaining an economically and biologically healthy commercial fishery. This would suggest that the fisheries manager should encourage the adoption of economically efficient commercial fishing techniques and attempt to eliminate excess capacity and manpower from the fishery.

Maintenance of Fisheries-Related Employment Opportunities

Many of the government's most important social objectives lean heavily on employment for their attainment. Better housing, public health, and education, as well as political stability and national security, are adversely affected if a nation's human resources are not effectively applied. Therefore, the creation of jobs and diminution of unemployment has been a primary concern of most free enterprise governments since the end of World War II. What is beneficial for a nation is not necessarily beneficial for a particular industry. An increase in a nation's employment opportunities may help to eliminate many social ills, but it is not always desirable to increase employment in a single industry. This is true in the fishing industry. Since overcapitalization is present in practically all of Canada's fisheries, an increase in fishing employment would almost certainly lead to lower fishing incomes, less economic stability among fisheries workers, and further dissipation of the resource.

It should also be understood that any policy aimed at increasing fisheries-related employment may have a negative impact on the fishery and an almost imperceptible effect on the total employment. In other words, the use of the fishing industry to create employment may be justified in some parts of the country where a substantial portion of the population is unemployed and traditionally there is a heavy dependence on the fishery. But in some areas where only a small percentage of the total employment is related to fishing, because of a limited resource base, the potential impact of fishing on employment is minute. Therefore, unless it can be demonstrated that there are special social virtues in fishing, jobs should be provided through the usual fiscal and monetary mechanisms.

Minimization of Social and Economic Disruptions

Fisheries managers usually suffer from two basic misconceptions when designing programs to minimize social and economic disruption. The first is that all social and economic disruptions are necessarily bad. The second is that any program that increases or maintains income and employment helps to minimize social and economic disruptions and is therefore good. Neither of these assumptions is true. Many of the world's greatest and most extended periods of social disruption have ultimately benefited mankind. The industrial revolution was a period of tremendous social and economic disruption and of tremendous headway in improving man's welfare. Similarly, the introduction of industrial assembly lines in the United States caused social and economic upheaval to the long range good of the United States and the rest of the world. Change and evolution are an inevitable part of living. Whenever man has attempted to prevent change, rather than to shape its direction, it has been to his own detriment. Attempts to increase or maintain income and employment by encouraging the development of economically unviable business enterprises usually create rather than eliminate social hardships. In fact, business failures, changing income levels, and temporary unemployment serve to encourage labor and capital to shift from low to higher performance areas which are of greater benefit to society. It is the process whereby thousands of businesses go bankrupt each year, while other Canadians start up thousands of new businesses, which by clearing the business community of inefficient producers, helps to

maintain a healthy business community and a high standard of living for all Canadians.

There are a number of factors present in the fishing industry that create social and economic disruption: heavy dependence on world markets and the necessity of regulating fisheries according to their biological need are disruptive; the secular and cyclical nature of the fisheries resource itself helps to perpetuate a "boom" or "bust" atmosphere. From a fisheries management perspective, it is the speed with which new legislation is adopted and implemented that causes economic and social hardships. These hardships can be particularly acute in coastal areas, where whole communities or groups are totally dependent on the fishing industry (Sinclair 1971). Therefore, fisheries managers should not develop programs aimed at maintaining economically unviable operations or attempt to eliminate change. They should introduce changes that improve the economic efficiency of the industry and that would mold it into patterns that prevent the need for sudden disruptions. A management system that is to the long-run benefit of the industry and that allows those associated with the industry to adjust to market changes and the changing biological limits of the resource would dispel a considerable amount of social and economic disruption.

Although there are many compelling reasons why fisheries managers are concerned with social disruption, this concern should not be used as an excuse for not adopting changes necessary for the maintenance of a healthy fishing industry. Aside from the fact that the fishing industry, just like any other Canadian industry, can be expected to suffer business failure and unemployment, it is the presence of excessive capital and labor in the industry that perpetuates a considerable amount of social hardships. The elimination of excessive labor and capital is consistent with minimizing social disruptions and maintaining a healthy commercial fishing industry.

Creation of Public Awareness About the Importance of Maintaining Healthy Fish Communities and Ecosystems

The creation of public awareness as a goal worth pursuing by fisheries managers appears, on the surface, to have considerable merit. However, there is some ambiguity with respect to this goal. Despite the fact that government-supported environmental agencies have not always received the resources necessary to carry out their responsibilities, it is not at all clear that the Canadian public is unaware of the nature and importance of safeguarding fish communities and their aquatic systems.

There is a need for meaningful and effective communications between government fisheries managers and the general public. This communication should be aimed at informing the public rather than creating public awareness. The problem of managing publicly owned resources is complex and often difficult to understand. Fisheries managers should try to keep the public informed about the consequences of individual developments. In this regard, it is important to remember that the fisheries resources of Canada are managed under conditions that tend to dissipate total economic rent through the excessive inputs of capital and labor, i.e. in a manner that provides little return for the people of Canada and almost certainly poses some threat to the resource itself. The economic rent from the fisheries could be retained and the threat to the fish stocks diminished by merely reducing the number of vessels and persons employed in the industry. There is considerable reluctance to take this approach because managers have apparently decided to forego economic rents in exchange for providing employment for unskilled workers, keeping families off welfare, and maintaining a way of life for specific segments of the population without fully appreciating that the welfare of the resource is involved. Only when it is possible to supply reasonable estimates on the amount of economic rent that is dissipated in fisheries because of these concerns, are fisheries administrators in a position to know the importance of maintaining the environment and to make informed decisions on such trade-offs (Crutchfield and Pontecorvo 1969; Bell 1970; Gates and Norton 1974). Furthermore, only when the public is informed about the amount of economic rent and resource that is dissipated will they be in a position to understand the value of the trade-offs involved.

Fisheries managers, like other government employees, have a responsibility to make the public aware of the good that they are doing for society. The public cannot be expected to support programs that do not have a demonstrated public benefit. If the public fails to recognize the true value of Canada's fisheries resources perhaps it is because fisheries managers have displayed considerable reluctance to accept the value of economic analysis for identifying trade-offs that are in the best interest of all Canadians. Although imperfect, economic analysis is the only acceptable tool for identifying social trade-offs in a rigorous manner. It is not necessary when using economic analysis to measure all costs and benefits in dollars. However, it is the dollar value to which the public most readily relates and accepts as a yardstick for establishing true worth.

As noted earlier in this paper, a great deal of care has to be used when soliciting public opinion. Unfortunately, public officials often attempt to solicit public opinion by gathering the opinion of vested-interest groups. Information gathered in this manner can be used, but it should be used with a great deal of discretion. The fisheries resources in Canada are owned by the Canadian public. Far too often, attempts to involve the general public through direct contact do not encourage the type of response necessarily in the best interest of all Canadians. Those directly benefiting from the fishing industry, just like other segments of society, can be expected to advocate those decisions that would

favor their own positions. Public officials should recognize that decisions that favor special segments of society may not be in the best interest of the general public. Once again, economic analysis can be useful for identifying decisions that are in the best public interest.

Attainment of Economic Efficiency

Since the primary emphasis in this paper has been economic efficiency, it is unnecessary to repeat all the advantages of operating a fishery subject to economic rationale. It should be clear from the foregoing discussion that economic efficiency is not only an element worth pursuing, but an essential part of fisheries management. With some qualifications, economic efficiency is consistent with all of the main areas of concern identified (Anon. 1976). Economic efficiency will help to improve commercial fishing incomes, minimize social and economic disruptions, create public awareness about the importance of maintaining fish communities and other related resources, and help to generate benefits for the Canadian taxpayer. Serious pursuit of economic efficiency necessarily implies that Canadian fisheries will not be sacrificed to maintain welfare programs that have questionable merit.

Fisheries Management Alternatives

The foregoing discussion has established that overcapitalization and indiscriminate free fishing have been recognized problems in Canada's commercial fisheries for more than 100 years. It also suggests with some qualifications that the pursuit of economic efficiency and the elimination of excess capacity is consistent with many, if not all, of the fisheries manager's most important concerns. In what follows, a number of fisheries management alternatives are presented for eliminating excess capacity. Each alternative is examined with respect to the following criteria:

(i) the extent to which it will accomplish a reduction in the fishing fleet and contribute to the continued existence of a healthy resource,
(ii) its political acceptability and administrative feasibility,
(iii) fairness of application and distribution of benefits among different segments of society,
(iv) the degree to which the management system would help dampen social disruption,
(v) the extent to which the management system creates a distortion of labor and capital inputs and generates economic inefficiency.

It is almost impossible for anyone but an elected official to determine explicitly the political reality of a particular alternative. It should be recognized, however, that fisheries administrators are in a position to help political leaders make good decisions by providing them with information on the public acceptability of particular management strategies, and the advantages and disadvantages of particular alternatives. The discussion carried out in this section should contribute to this endeavor.

Nonpriced Limitations on the Number of Production Fishing Units

The most obvious method of controlling fishing effort and reducing excess capitalization is to impose a free license on either the fishermen or the vessels and restrict the number of licences issued. The main advantage of this approach is that any reduction in the number of fishing units will reduce harvest costs. Insofar as such a scheme does in fact reduce fishing effort and consequently costs, it would benefit the fishermen, the resource, and society in the short run.

Unfortunately, there are a number of practical and administrative difficulties associated with this method. The most serious is that it does not eliminate the underlying incentive for the individual fisherman to introduce larger and more costly vessels in order to compete with other fishermen and to ensure a greater share of the catch (Campbell 1970; Sturman 1976). Therefore, the overall result is for continued overinvestment in the fishery.

The use of this method would also require fisheries managers to make continual adjustments in the number of fishing units licensed to participate in the fishery. This would be required for two reasons. First, there would have to be a readjustment in the number of fishing vessels over time to offset the improved harvest power of the fleet as new and better boats are introduced into the fishery. Second, the number of units participating in the fishery would have to be altered so that the production capacity of the fleet coincides closely to the changing biological limitations of the resource. Since the returns to each fishing unit could be expected to increase considerably as the total number of vessels and fishermen participating in the fleet decline, there would be tremendous incentive for each fisherman to try and gain competitive advantage by investing further in his vessel. This reaction complicates considerably the problem of predicting the catch potential of the fleet and calculating the optimum fleet size.

Another related problem when using this alternative is whether to restrict vessel or individual fisherman licenses. In the absence of government intervention, the vessel owners could be expected to employ the optimum combination of manpower and capital for any amount of effort in order to maximize their net returns. If the vessels are subject to restrictive licensing, the vessel becomes a scarce commodity and attempts will be made to increase catching power by increasing the number of deckhands. On the other hand, if fishermen are subject to restrictive licensing, they will become the scarce factor and there will be incentive for the vessel owners to overcapitalize. In either case, the overall effect would result in serious economic waste and pose the same threat to the resource as would occur in the absence of a

licensing system or a rationalization program (as discussed in the previous sections).

An equally serious problem is that the resource rent would become capitalized into the private value of the fishing license regardless of whether or not it was a personal or vessel license. This will occur in any licensing system where the fee is less than the full capital amount that the market will bear (and the resource rent is not captured). The overall result would be for the rent from the resource to accrue to the individual license holder or licensed vessel owner, rather than to the general public.

Finally, there is no equitable method for distributing free licenses. Since one of the primary objectives of a licensing program is the attainment of economic efficiency, it would seem reasonable to distribute licenses among the most efficient operators. It would also seem reasonable to expect that any method that distributes free fishing licenses should be done on an equitable basis. Yet there appears to be no acceptable method for distributing free licenses so that they meet these two criteria. Distribution of commercial licenses through a lottery, or some other supposedly random method of allocation, would fail consistently to provide a license to those members of society who would value the license the most. Any licensing system where the fee is less than the market can bear can be expected to encourage individuals to sublease their license, thereby capturing the revenue that the licensing agency would normally collect for the public treasury. A lottery system would create uncertainty and might help to idle some of the labor and capital already committed to the fishing industry.

The use of nonpriced licenses for reducing fishing effort would fail to ensure that fishing rights are received by the most efficient production units, fail to eliminate the incentive for individual fishermen to overcapitalize or to use excessive labor, leave the resource rent in the hands of participating fishermen or vessel owners (rather than the public), present serious administrative problems in the allocation of fishing privileges, and would not help to ensure a safe level of harvest.

Pricing as a Method of Rationing Harvest and Limiting the Number of Fishing Units

Another alternative is to issue fishing licenses at a fee that would just clear the market. This would raise the private cost of fishing to a level commensurate with the optimum size of the fleet and a level of fishing effort consistent with protecting the resource and maximizing economic returns. This would, in effect, serve as a device for limiting harvest levels and help to protect the resource. This management alternative offers several other advantages. It would ensure that only the most efficient fishermen would receive a fishing license. It would also solve the problem of allocating licenses and would help to ensure that the public treasury receives the resource rent.

Unfortunately, this alternative has some disadvantages. Most importantly, this method depends almost entirely on the resource manager's ability to determine and charge the *correct* license fee. If the correct market price for a license encourages optimal use of the resource, it follows that an incorrect license fee would encourage either over- or underutilization of the resource. Since there is no foolproof method for determining the correct market fee and since fishermen could be expected to lobby for a lower rather than a higher license fee, an artificially established license fee would likely encourage overutilization of the resource. Second, depending on whether the individual or the vessel is licensed, this system would either encourage excessive labor input or excessive capital investment. Third, this system favors full time over part-time fishermen. Any system that puts part-time fishermen at a disadvantage would be socially harmful to this segment of society.

A fourth problem with this method is that it would not provide the resource agency with sufficient control over the fishery. Since this alternative encourages only the efficient operators to participate in the fishery, control of the fish stocks may fall into the hands of a few highliners or even a single processor. This may not be considered a serious shortcoming by many since control of the fishery by a monopoly would almost certainly discourage overfishing (if the fishery were controlled by a single group or individual, it would be in their best interest to protect the continued existence of the resource). Despite the fact that this is a debatable issue, almost everyone is familiar with the undesirable impact of monopolies on the consumer.

Finally, for this system to work, it would be absolutely necessary for only the government to participate in the sale of fishing licenses. For this reason, it might be argued that the resource agency would have to guarantee the right of individuals to purchase licenses over an extended period of time in order to provide them with the opportunity to recover their investment. However, this simply would not work. An extended licensing period would not necessarily provide the individual with the opportunity to recover his investment. Since the level of fishing effort (assuming use of the *correct* license fee) would have to be changed every year, a person may enter a fishery one year and find it economically inexpedient to participate the following. Moreover, the use of an extended licensing period also may be unwise because it would encourage some fishermen to attempt to recover their total investment during the life of the license. Since the expectations of the fleet may not be commensurate with the harvest capacity of the stocks, this may pose a serious threat to the continued existence of healthy fish communities.

Tax-on-Landings or Royalty System

An alternative considered particularly attractive by

many resource economists involves the levying of a tax, royalty, or landing fee on each pound of fish caught (Pearse 1971). Since there is a natural tendency for the fleet to expand fishing effort to the point where costs equal revenue, the adoption of a tax on landings would serve to encourage a new equilibrium at a lower level of fishing effort. An appropriate fee would reduce fishing effort to a point where excess capacity no longer poses a threat to the resources.

There are many attractive advantages of a tax-on-landings system. The first of these is that a tax on landings would not distort the form of fishing effort and the incentives to adopt new technology would remain unchanged. Since landed fish are always weighed or counted, the adoption of this system should not pose any serious administrative problems. Unlike the licensing systems outlined above, a tax on landings would not impose additional risks and uncertainties on fishermen. The fishermen would pay taxes only on the realized catch. When landings are great and fishermen's earnings are high, the revenue earned (or resource rent captured) by government would be correspondingly high. When landings are low and fishermen's earnings are poor, the resource rent would be low also. A tax on landings would enable the resource agency to charge variable rates to discourage the harvest of threatened or endangered species. Progressive tax rates could be used to limit actual harvest or the rates could be adjusted in a manner to improve the overall quality of the catch. More important from a social point of view, the royalty system would not discriminate among fishermen. The fleet would continue to comprise full-time, part-time, efficient, and inefficient fishermen. It has been noted that a fishery rationalized by a tax system is likely to be characterized by lower aggregate costs, greater labor employment (of both productive and less-productive workers), and more efficient harvesting techniques (Pearse 1971).

The only serious shortcoming with this method is the misunderstanding that might accompany the adoption of this type of system. Many fishermen would be under the impression that a tax on landings would reduce their earnings by the amount of the tax. However, this is not true. The tax on landings would *not* reduce fishermen's earnings. If the tax were introduced at a low rate and gradually increased, then the tax would have an almost imperceptible effect on fishermen's earnings in the short run. In the long run, the full amount of the tax may be passed on to the consumer. As the fleet declines the average earnings of the fishermen should substantially increase. The theoretical and practical underpinnings of this approach have been fully established and have been practised by resource agencies responsible for managing and allocating Canadian resources for many years.

In short, a tax on landings or royalty would not distort the form of fishing effort; it would improve the economic efficiency of the industry, help to ensure that the resource rent is passed on to the public, improve the earnings of individual fishermen, and encourage a level of harvest consistent with the biological capacity of the resource.

The Grandfather Alternative

One alternative often adopted in conjunction with other management schemes is the "Grandfather System." The "Grandfather System" is a scheme whereby each fisherman and each owner of a vessel is issued a nontransferable, lifetime license. As fishermen or owners of fishing vessels die or retire the license is withdrawn, thereby reducing the size of the fleet over time. This system's main advantage is that it can be used in conjunction with other management schemes to overcome transition or implementation problems. It helps to protect the investment of existing fishermen and, as a consequence, is readily acceptable to those already in the industry.

This alternative, like other licensing systems that are meant to solve the problems of overcapitalization, has a number of shortcomings. First, it encourages fishermen to remain active as long as possible in order to protect the increasing value of their fishing rights. Second, it precludes the adoption of new technology and the entry of new low-cost production units. Third, the resource rent will accrue to the established fishermen at the expense of those who cannot gain entry to the fishery and the general public. Fourth, it provides no satisfactory method for replacement or the distribution of fishing rights. Fifth, it serves to distort labor and capital inputs. Finally, this method of rationalization is painfully slow, and in those situations where it is absolutely necessary to adopt some form of rationalization in order to protect the fishery, the positive effects of such a program may not occur fast enough to provide such protection.

Since this alternative favors those already in the industry, it has a strong appeal. However, it should be remembered that this method favors existing fishermen at the expense of the introduction of new, and perhaps, more progressive fishermen. If this method were adopted on a province or nationwide basis, it would increase the cost of Canadian fish and substantially decrease foreign fish sales. It would not serve to improve the economic efficiency of the industry and probably work to the serious disadvantage of the Canadian consumer.

Recommended Management System for Canada's Fisheries

As in many other areas, there is no unanimous diagnosis and treatment for sound biological and economic management of fisheries resources. Nonetheless, there has occurred over the last 15 years a tremendous surge in the amount of recognition given to the common property problems of fisheries. There has been also a large number of programs established to offset these

problems and to implement schemes that will serve the interests of the resource, the industry, and the general public. Thus, there is much that can be learned from what has taken place in fisheries throughout the world. The first and most obvious lesson is that problems associated with managing all large-scale commercial fisheries are essentially the same. The complications created by international participation or characteristics unique to only particular fisheries (including many social or welfare considerations) merely serve to make the adoption of a rationalization scheme more difficult. These factors do not eliminate the need for such programs, the possibility of successful introduction, nor the responsibility of fisheries managers to utilize the most progressive techniques available.

A second lesson that can be learned from existing rationalization programs is that most jurisdictions contain more than one type of fishery. Many contain both a sports and commercial fishery; many contain small subsistence fisheries and large-scale commercial operations. Rules that are applicable to one fishery may not be appropriate for another. Nevertheless, a good management system should include within it a certain amount of flexibility to take into account the wide differences encountered in most jurisdictions.

The management scheme that most appropriately follows from the criteria discussed above encompasses a simple licensing scheme, a tax or royalty on catch, and a limited variation of the "Grandfather System." It is intended that a combination of the three main alternatives will incorporate the main advantages of the alternatives while avoiding their main shortcomings.

As already noted above, rationalization programs based on licensing pose many difficulties which almost totally nullify any hope of achieving an efficient and effective management system. However, this does not imply that licensing programs cannot be used effectively in conjunction with other schemes to generate revenue, to facilitate management control, and to provide information on the users of the resource. All vessels and fishermen in Canada should be licensed. Fishermen should be required to purchase an annual license for their boats. Since the licensing system is not meant to serve as a method for reducing excess capacity in the fleet, the fees paid should be low enough so that they do not prevent any serious fishermen from participating in the commercial fishery, but high enough to represent a serious purchase. The main reasons for licensing are to provide a tool for gathering up-to-date information and to serve as a mechanism for maintaining control.

The number of participants in Canada's commercial fisheries can be reduced by adopting a variation of the "Grandfather System" and by introducing a per pound tax on landings. This could be accomplished by freezing the total number of vessel licenses issued, prohibiting transfer of any of the existing vessel licenses, and withdrawing all licenses not currently active or being used by those possessing them. As the number of fishing units diminishes and the average income of the fishermen rises, a per pound tax on landings could be slowly introduced. Once the number of fishing units has declined to some artificially determined (not necessarily precise) number of fishing units, the royalty system could be put into place without posing any economic hardship on individual fishermen. In fact, if done properly, the royalty could be introduced in a manner that allows fishermen to realize a slow but moderate increase in their earnings over the transition period.

Once the number of fishing units is reduced to a level consistent with the harvest capacity of existing stocks, and the tax on landings has reached a level where it captures a substantial portion of the existing resource rent, then there may not be a need to maintain the freeze on licenses. The tax on landings would serve as a mechanism for preventing overexploitation and overcapitalization. No restrictions on changes in vessel capacity or their disposition will be necessary, and once again, there will be a normal market for boats and gear. The system will have to be continually monitored to ensure that the tax on landings is sufficiently high so that it does not encourage overinvestment and overexploitation of the resource and is low enough so that it does not discourage too many fishing units from participating in the fishery (destroy the ability of the fleet to effectively harvest the stocks). However, there should be enough money generated from the royalty to pay for this added surveillance and enough information available from the licensing system to facilitate this type of monitoring. As the excess capacity in particular fisheries declines, additional efficiencies could be realized by removing gear, catch quota, and fishing-period restrictions so that the productivity of effort is substantially increased. This would lead to a demonstrable rise in fishing incomes.

There are a number of administrative details that would obviously affect the acceptability, effectiveness, and equity of this approach. Among the more important of these which have been utilized in other rationalization programs are

1. To maintain the integrity of the licensing system as an effective control method, it is necessary to issue only one license per fisherman and per vessel. Multiple licenses could be issued as a single licence that would permit fishing in more than one area.
2. To ensure equity and to encourage the participation of those most directly affected by this system, appeal boards could be established. Boards comprising representatives of industry, commercial fishermen, and economists would be responsible for reviewing appeals and helping fisheries managers establish a criterion for identifying inactive fishermen.
3. The fisheries managers may wish to consider a method of compensating fishermen (i.e. buy-back program, etc.) for the loss of fishing rights during the early years of the program, since this would not necessarily alter the effectiveness of

the program (although it may increase the speed with which fishermen would wish to exit from the fishery). Economic analysis cannot provide any insight into the correctness of this approach, although it should be understood that economic analysis can help to determine what would be a reasonable amount of compensation.

These arrangements combine the economic and administrative virtues of a licensing program, a royalty system, and the "Grandfather System." The licensing program would provide fisheries managers with both the ability to control the fishery and a mechanism for gathering information. The royalty would stimulate economic efficiency, eliminate overcapitalization, improve fishing income, discourage overexploitation of the resource, and generate an economic rent for Canadians. The "Grandfather System" would ensure that there is a minimum of social disruption by permitting continued employment of low-income or immobile fishermen. This feature of the program helps to facilitate an easy nondisruptive transition from the existing administrative procedures to the new program by protecting established fishermen. This program, at least, has the merit of using economic means instead of arbitrary regulations to achieve socially and economically desirable objectives and to ensure protection of the resource. In other words, to some degree, it does help avoid the preponderance of government regulations, which interferes with the free operation of the fishing industry.

Sport Fisheries

Management of fish stocks encompasses more than simply administering commercial fisheries. Sportfishing can be expected to increase rather rapidly in future. Thus, an ever increasing portion of Canada's fisheries resources will be utilized by resident sport fishermen and foreign visitors. Like commercial licensing, sport-fish licensing serves three basic purposes. It provides information, generates revenue, and facilitates control. In the interests of equity and of attaining total rational resource management, sport-fish licensing should be adopted throughout Canada. The license fee should be sufficiently high to help pay for some of the expenses borne by Canadians for sport-fisheries management. In this regard, it is important for fisheries managers to recognize that the sport fishery is a public and a private good (Sinclair 1975); that is, sportfishing is an activity in which practically all segments of the population participate. It is a public good that provides a tremendous amount of social benefit just like police protection, education, and navigational aids. However, it is also a private good that supports many private business enterprises (i.e. marinas, motels, fishing resorts, etc.). As a private good, there is no reason why nonfishing members of the general public should be required to subsidize sport fishermen through their taxes. On the other hand, as a partial public good that generates considerable social benefits, there is considerable merit in committing a certain level of government expenditures to provide the public with sportfishing opportunities. There is a level of public sportfishing expenditures consistent with generating optimal social benefits (Sinclair and Reid 1974).

On the basis of the tremendous amount of information gathered by fisheries resource management agencies throughout North America, it is difficult to believe that the decision not to have sport-fish licensing in some areas of Canada is consistent with the needs and wants of the people. It has been found that fishermen generally favor sport-fish licensing for three reasons:

1. Revenue from licensing helps to pay for programs designed to improve sportfishing and protect the resource. Even if such funds are not earmarked for sportfishing, it helps to instill a sense of importance about sportfishing among politicians.
2. It gives sport fishermen a sense of pride because they feel that the license fees that they are paying help to maintain the resource.
3. It gives sport fishermen a certain amount of legitimate political power; as paying users of the resource, they should have some legitimate say about how the resource is utilized.

It is important to remember that dependable estimates on the value of recreational fishing will be needed in future. This will become increasingly apparent as sportfishing in Canada continues to increase. An urgent need, therefore, is to maintain sport-fish licensing programs to provide mechanisms for data collection and to generate revenue for financing fisheries development programs.

Other Related Issues

Two issues, which are not discussed above, that bear on policies of rationalization for Canada's commercial fisheries are international constraints and environmental protection. In the case of international fisheries, rationalization ideally should proceed concurrently in fisheries of all commercial-fishing nations. However, this is not likely to occur when many different nations have recognized traditional rights. Nonetheless, protection of the interests of Canada could be enhanced considerably if national shares in the permitted harvest are allocated under an international commission or some other similar regime (i.e. International Commission of Northwest Atlantic Fisheries).

Although environmental protection is important to fisheries resource management, inadequate provisions for the environment should not serve as justification for not adopting a rational fisheries management system.

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The Need for Human Sciences Research in Atlantic Coast Fisheries[1]

R. ANDERSEN

Memorial University of Newfoundland, St. John's, Nfld. A1C 5S7

Contents

ABSTRACT/RÉSUMÉ 1031
I. CHALLENGE AND DILEMMAS IN TRANSFORMING EAST COAST FISHERIES 1032
What are Fisheries in Human Terms?
Global Setting for Fisheries
Human Sciences Problems in Atlantic Canada's Fisheries Development
Atlantic Fisheries
Atlantic Fisheries Contribution to Canada and to the Region
The Fishermen
Atlantic Fisheries Fleet
The Catch
Plant Employment
Vertical Integration
Development Priorities for Atlantic Coast Fisheries
Atlantic Coast Fisheries — Who shall fish?
Access Problem
Conclusion
II. PRIORITIES FOR INVESTIGATION 1043
III. CURRENT HUMAN SCIENCE RESEARCH EFFORT IN ATLANTIC FISHERIES 1044
Centers of Expertise and Capability in Human Sciences
Laval University
Memorial University of Newfoundland
Dalhousie University
Priorities for Mobilizing Human Sciences in Atlantic Coast Fisheries
ACKNOWLEDGMENTS 1048
REFERENCES 1048

Abstract

ANDERSEN, R. 1978. The need for human sciences research in Atlantic Coast fisheries. J. Fish. Res. Board Can. 35: 1031–1049.

Canada's coastal fishing industry is changing in response to recent international agreement permitting coastal states to extend jurisdiction over fish and fishing to 200 miles from their shores, the appreciation that renewable aquatic resources can be harvested easily to a point of nonrenewability, the current economic conditions in the world giving rise to spiralling prices, inflation and unemployment, and political developments specific to Canada. I argue that by controlling changes in the fishing industry it is possible to optimize the social benefit to the nation and that two routes are available to attempt this, by additions to existing structures and by qualitative restructuring. But, above all else, I stress that fishing, as a modern enterprise, cannot be isolated from the livelihood and benefits of those most dependent on the harvest from the sea. In order that the results of change can work to optimize the social good, I indicate where lack of knowledge in human and social terms precludes rational decisions or policy shifting towards qualitative restructuring of the fishing economy. The results of additive changes are summed up — "Additions call for more of the same, with temporary improvements possible for some, until our growth prospects meet the limits of renewed stocks available to us under preferential fishing within the 200 mile management zone."

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Résumé

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L'évolution que connaît la pêche sur les côtes canadiennes est due à plusieurs facteurs: les récents accords internationaux qui autorisent les États côtiers à étendre à 200 milles du littoral leur compétence en matière de pêche et de poissons, la découverte que la surexploitation des ressources aquatiques renouvelables peut être irréversible, la hausse vertigineuse des prix liée à la situation économique mondiale, l'inflation et le chômage, enfin la conjoncture politique canadienne. En maîtrisant ces changements, il est possible d'optimiser les avantages sociaux que la nation peut en retirer; il existe deux voies pour arriver à ce résultat: adjonction de structures complémentaires et restructuration qualitative. Avant toute chose cependant, la pêche, en tant qu'activité moderne, ne peut être dissociée du mode de vie et des avantages sociaux de ceux qui dépendent des ressources marines. Pour que les résultats des changements puissent contribuer à améliorer la situation sociale, nous avons indiqué les secteurs où les lacunes du savoir en sciences humaines et sociales empêchent que des décisions ou des politiques rationnelles ne soient appliquées à une restructuration de l'économie de la pêche. Les résultats de l'adjonction de structures complémentaires sont résumés ainsi: "Les nouvelles structures doivent être du même type que celles qui existent actuellement, certaines améliorations temporaires pouvant être introduites dans certains cas, jusqu'à ce que nos perspectives de croissance rejoignent les limites des stocks rétablis dont nous pouvons disposer du fait de notre prérogative de pêche dans la zone économique des 200 milles."

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A People Policy for Fisheries

Although commercial fishing has long been a highly regulated activity in Canada, the object of regulation has, with rare exception, been protection of the renewable resources. In other words, fishing has been regulated in the interest of the fish. In the future it is to be regulated in the interest of the people who depend on the fishing industry. Implicit in the new orientation is more direct intervention by government in controlling the use of fishery resources, from the water to the table, and also more direct participation by the people affected in the formulation and implementation of fishery policy.

Policy for Canada's Commercial Fisheries (Anon. 1976a).

I. Challenge and Dilemmas in Transforming East Coast Fisheries

The extension of Canadian fisheries jurisdiction to 200 miles on January 1, 1977 commences a new era in domestic and international fisheries off our East and West coasts. We have taken a large step beyond our previous 3- and 12-mile jurisdictional zones, with consequent increased responsibilities for scientific research to manage fishery stocks and for protection and enforcement in this area. Opportunities also exist to enlarge Canada's share of stocks under this new jurisdiction.

The changes inherent in this new regime, however, can be depicted as merely additive for several reasons. *First*, extended jurisdiction has not eliminated foreign fishing from and around this zone, nor do all important stocks come under our management control; both the Flemish Cap and southern and eastern portions of the Grand Bank remain outside the jurisdictional boundary.

Second, decisions about stocks surplus to Canada's requirements remain subject to international scrutiny and remain influenced by considerations of foreign fishing fleet capacities and world food requirements. Extended jurisdiction is not an exclusive license for Canada to pursue her economic and social interests through good fisheries management. The stocks within the 200-mile zone are not yet ours; we have only restricted access to a common property resource.

Third, there is a basic difference between the "modernity" of our understanding of the marine biomass and decisions about how it should be harvested. Fisheries biologists recognize the need to depart from single-species stock assessment and the concept of maximum sustainable yield (MSY) in favor of viewing stocks in ecosystem terms, i.e. as interdependent species. This change transforms science and management in the areas of information collection, modeling, analysis, and projection. By contrast, the government approach to management and decision-making for harvesting, processing, and marketing remains essentially paternalistic and it is necessary to inquire to what extent, or if, this political structural component of fisheries requires change toward a self-determining system. This is especially true if yields are to be maintained at optimum social benefit levels. These are two fundamental dimensions of the larger approach to fisheries which may be summed up in various terms, none of them particularly elegant, e.g. "fisheries as social and cultural systems," "socio-political-subsistence systems," or simply, our "fisheries adaptation."

What are Fisheries in Human Terms?

In the larger meaning of the term, fisheries are activities through which people link themselves with the aqua-

tic environment and its renewable resources. The meaningful components of these activities (there are many ways to organize life around marine settings and stocks) include (1) *technology* (e.g. hooks and lines, traps, vessels, stock measurement techniques, and other hardware and patterns for their use); (2) *economy* (e.g. patterns of access to resources, labor and investment incentives, institutions, markets, middlemen, entrepreneurs, consumers and their preferences); (3) organized *groups* of people (e.g. fishermen, their communities, processor–enterprise operators and workers, conservation and protection agencies, industry associations (unions, marketing groups, and trade councils), scientific experts (government and academic) and their associations); (4) *political* institutions (e.g. the structure of authority and power to make decisions affecting resource extraction, processing, distribution, cost and profit determination, and investment and planning decisions; and the legal and practical allocation of decision-making responsibilities among federal, provincial, and local governments, unions and employers, producers, buyers, and marketing agencies); (5) *values and myths* (e.g. the attitudes, philosophies, and assumptions about the "right order" of things which rationalize the relative power and choices of individuals and groups that compose and depend upon a fishery). Values and myths include the leading "-isms" of our time.

These components are found in all fishing societies, whether primitive, peasant, or industrial. They enable us to understand fisheries as variations on human adaptation evolving in response to internal and external societal changes. People meet these changes and make *choices* from among existing alternatives. Thus, fisheries are more than the sum of impersonal forces and conformity to tradition.

Fisheries adaptations are only partly explained by proximity to specific marine environments and resources. The variances embrace different technological levels, different relationships between primary producers, capital, markets, and governments and different institutions integrated with fisheries. For example, ownership of large fishing vessels in the Norwegian herring purse-seine fishery is by family groups, cooperatives, and individuals, and this is fostered by regulative controls and banking institutions (Wadel 1972). In Eastern Canada, offshore trawlers are owned mainly by nonfisherman processing corporations and are vertically integrated with shore plants. The Icelandic, Faroese, and Norwegian fisheries have long produced good quality saltfish (cod) for their export markets. The Canadian saltfish industry because of special circumstances of geography, etc., has long been antiquated and produced lower quality salt-cod for virtually the same markets (Innis 1954, p. 47; Alexander 1977). And where Scandinavian fishermen are highly politicized and active in all stages of fisheries development decision-making — production, processing, marketing, and finance, etc. — eastern Canadian fishermen remain rather peripheral in most of these matters (Andersen and Wadel 1972, p. 1–8).

Fisheries have undergone a remarkable transformation from prehistoric to contemporary times. Increasingly effective technologies have been developed to expand man's use of living marine resources. A complex division of labor (occupational specialization) has developed in the shift from paeolithic subsistence, through peasant, to modern labor production. And modern fisheries have become highly complex in their linkage with local, regional, national, and international markets, economies, and societies (Andersen 1974, 1978; Coull 1972; Clark 1948, 1966, p. 69–90). These general trends seem now to have led to "the tragedy of the commons" and to relentless competition for progressively decimated stocks. The global harvest of certain "traditional" fish has reached and in many cases exceeded the limits of renewability. The plight of world fisheries seems part of the greater litany of the contemporary "human ecological predicament" (Ophuls 1977, p. 222) which is provoking discussions of quantitative vs. qualitative change in our approach to resources everywhere. This larger human ecological predicament forms the background of Atlantic Coast fisheries.

Which is the most important change? It is difficult, if not impossible, to assign primacy to any one factor. The question defies simple answers even in the case of relatively small, undifferentiated fishing societies (Legros 1977). When speaking of fisheries enmeshed in modern industrial and global societies the problem of understanding is writ large. Understanding demands that fisheries be viewed as part of a *larger* system always in process, and *always* requiring attention to its challenges.

Global Setting for Fisheries

Burgeoning populations and demands for food and energy, urbanism, industrialization, consumerism, and environmental degradation have triggered global economic instability which now reaches into nearly every corner of the world. This process is accompanied by a growing sense of alienation from the fundamental institutions of society and a widening gap between the structurally advantaged and disadvantaged. The destabilizing forces threaten industry, community, and polity in all states and policy and decision-making freedoms are progressively eroded. We seem to face a major "break" or discontinuity in human history and perhaps, as Wertime (1977, p. 17) argues, "the end of the world's golden age," when exponential growth, prosperity, and rising expectations must greatly decline.

Some experts are of the opinion that the industrial world's historical emphasis on narrowly defined economic growth "will now likely shift toward equity and just distribution" (Regier and McCracken 1975, p. 4). Thus, it seems to them, that the time has come to redress the excesses of an exploitative industrial order, and to move toward a "more conservationist and productive technical society . . . geared to more widespread output by more persons in small units (Wertime 1977, p. 18)."

Save for some frontier species and locations, world

fisheries already admit part of this change, including the need for careful management and allocation of stocks. Canada's fishery-stock allocation and management scheme for 1977, under extended jurisdiction, is one of the many structures that may need to adapt as we move from growth-oriented to steady-state fisheries.[2] In such adaptations, as Regier and McCracken (1975, p. 4) observe, "When all resources will have been 'fished up' further increases in the value of catches per se — aside from inflation and shifts in consumer preferences — will stem from improvements in various aspects of management and harvesting broadly defined. Improvements will involve ecological, technological, economic, and social initiatives." The implications of new allocation systems for the future of the fishing industry and particularly for those who have built their communities, occupations, and lives around it, are fundamental policy issues.

The new initiatives are part of an innovative process in fisheries which will have to be designed to foster diversified local and regional fisheries to utilize available stocks more effectively than in the past. Such innovations may include microlevel responsiveness that governments are inadequately equipped to handle effectively. Our future fisheries suggest new federal–provincial roles and responsibilities.

Human Sciences Problems in Atlantic Canada's Fisheries Development

This study prepared for the Human Sciences Committee (see Acknowledgments) of the Fisheries Research Board of Canada was, in part, motivated by the recent study by McCracken and Macdonald (1976) on the "Science for Canada's Atlantic Inshore Seas Fisheries" which assessed the biological science needs for intelligent decision-making related to the interests of some 56 000 fishermen and fish-processing employees scattered among an estimated 2000 small communities in the five Atlantic provinces. About 75% of the communities in the Atlantic region are involved in commercial fishing and "20% of these communities (roughly 250 000 people) have no other economic base" (Anon. 1976a, p. 7).

McCracken and Macdonald's (1976, p. 2) definition of biological science needs for the Atlantic inshore fisheries — with special attention to the east coast of Newfoundland and Labrador and the Gulf of St. Lawrence — was argued in a perspective of "a manipulative sociopolitical subsistence system which perpetuates high unemployment, low income, and much dependency on government." They considered three broad policy options for future fisheries development in Atlantic Canada:

1) "continuing contradictory policies and actions;
2) unionism, corporate mergers, more efficient and coordinated government action, and the inevitable power concentration, centralization, and shakeout of "fishless" ex-fishermen this would entail; and
3) substantial and creative changes."

In a carefully reasoned argument, they reject the first two options and press for the third, which is aimed at a "balanced corporate–noncorporate fishery and attempts to counter the manipulative system . . . measures which promote equity, productivity, and creativity."

The mandate for this study is to examine "what needs to be done to provide sufficient background knowledge in social science and its organization to permit beneficial development of fisheries activities in Canada." The directive derives from an appreciation that "the country has received a mandate only recently to manage the resource for maximum social benefit" (FRB Human Sciences Committee minutes, May 2, 1977). This mandate places greatest stress upon the contribution of fisheries to Canadian *national* interests, although presumably it derives from the Federal Fisheries Policy document (Anon. 1976a), which stresses that, unlike the past, where Canada has regulated fishing "in the interest of fish," it will now regulate "in the interest of the people who depend on the fishing industry." The difference between managing for "maximum social benefit" or for "the people who depend on the fishing industry" invites continuation of contradictory policies as pointed out in the McCracken and Macdonald (1976) analysis. The difference leaves room for uncertainty about the congruency between national and "fisheries people" interests. Is there cause to ponder where the power over decisions affecting fisheries and coastal societies really ought to lie and whether alternative structural arrangements might be desirable for both fisheries people and national interests? This matter will be considered later.

In what follows I attempt to outline the nature of the Atlantic fisheries adaptation and to identify human science research needs pertinent to fisheries development during the next 10 years. (Ten years is the period of time many fisheries authorities feel to be necessary to restore fish resources to a level from which we can build a steady-state fisheries, and to assess the best techniques for effective long-term management.) The study will then outline recommendations and propose a research program pertinent to these human science needs.

The study concentrates on the Atlantic fisheries for

[2]The distinguishing characteristics of a "steady-state" or balanced fishery remain to be defined. Only relatively locally confined fisheries and single-species fisheries have approximated such circumstances in management and fisherman adjustment (e.g. the Chesapeake Bay oyster fishery, and the Cornish oyster fishery; Cove 1973, p. 13–15). Little is known about the larger social and cultural effects of such fisheries apart from conventional concepts of more restricted access to grounds, quota, and gear restrictions, and presumed fishermen attitudinal changes toward their stocks and occupation. We may only partially extrapolate findings from such fisheries, especially those in other nations, to the multispecies management setting that faces Canadian fisheries interests, fishermen, buyer–processors, and managers.

several reasons: Unlike the Pacific, Atlantic fisheries management and development are politically more complex, e.g. five provinces as compared to one. Atlantic fisheries are also more highly diversified and employ over two thirds (56 000) of those working — including both primary and secondary sectors — in Canada's fisheries. But in 1972, its fisheries returned only $269 million, while the 15 000 persons employed in the Pacific region returned $127 million. Combined federal and provincial government expenditures designed to keep Atlantic region fisheries "alive" have averaged about $140 million annually for the period 1974–76 (Anon. 1976a, p. 19). This amount appears to exceed direct government revenues from these fisheries, although indirect revenues from the impact of commercial fishery activity on other industrial sectors may temper this impression. In short, the commercial fisheries of Atlantic Canada are of special national and regional concern and, in my view, it is to this region that the 1976 Federal Fisheries Policy statement is particularly directed.

Notwithstanding this special focus, some of the findings are applicable nationally. The study does, after all, concern people adapting to coastal marine settings, exploiting marine resources managed by government specialists who, presumably, employ a common management approach, and its industries and markets operate in the same national and international sociopolitical subsistence system.

Data for this study were obtained from interviews with "spokesmen" from labor, buyer–processors, representatives of provincial and federal governments, and social scientists involved in research in the Atlantic provinces; participation in several fisheries-related conferences;[3] documentary materials; and impressions and information gathered prior to this assignment.

Atlantic Fisheries

The fisheries of Atlantic Canada can be described in a variety of ways, but none of these is more than an approximation of some part of this complex and dynamic fisheries adaptation. The conventional approach relies on "concrete" statistical categories of men, boats, productivity, and value, but there is a difference between a statistical representation and reality for discrepancies occur in our data due to time lag, input failures, and weaknesses in current information acquisition and retrieval systems. Thus, these data only approximate reality.

Atlantic Fisheries Contribution to Canada and to the Region

In 1974 the fisheries of Canada contributed 0.8 to the value added by all commodity producing industries and employed 78 000 people (0.8%) out of a total labor force of 9 097 000. The following data, however, indicate that in the Atlantic region the contribution by fisheries to value added by all commodity producing industries is much greater (Anon. 1976b):

	$\times 10^6$ $	% of all commodity producing industries
N.B.	51.3	3.9
Nfld.	86.8	8.7
N.S.	132.4	10.7
P.E.I.	16.7	10.2
Que.	26.2	0.2
Total	313.4	1.7

In similar fashion, the following data indicate that work in fishing and fish processing plays a far greater role in total employment in the Atlantic region than is indicated in the national average (Anon. 1976b):

	Fisheries	Employment	%
Nfld.	21 000	148 000	14.2
Maritimes	26 000	540 000	4.8
Que.	7 000	2 411 000	0.3
Total	54 000	3 099 000	1.7

Thus, in Newfoundland, for example, about 14.2% of the labor force is employed in fishing and processing. The *Policy for Canada's Commercial Fisheries* (Anon. 1976a, p. 12) states

> "The [Newfoundland] industry's influence is pervasive: for every job created or lost in fishing, 0.4 jobs are created or lost elsewhere in the province; for fish processing, the ratio is 1.0 to 1.8. In Nova Scotia (where the fish business accounts for 10 to 15 per cent of value added in all community production) these ratios are even higher, at 0.7 and 2.3. In terms of how each dollar of industry output affects provincial household income, only parts of the forest industry have greater impact in the province. The fishing industry has strong links with shipbuilding and service industries in this and other regions of the country. The fisheries are the sole reason for the existence of many coastal communities. If they were to fail, the economy of the area would founder and the people involved would be forced to migrate."

[3]These include the following: Newfoundland Fisheries Systems Management Conference, St. John's (October 1976); 1977 Fisheries Management Plan meeting with the Honourable Roméo LeBlanc and fishermen representatives from Quebec, New Brunswick, and Prince Edward Island, Charlottetown (October 1976); Canadian Conference on Freshwater Fisheries Research, Fredericton (January 1977); The Future of the Offshore; Legal Developments and Canadian Business, Dalhousie University, Halifax, and contribution to the Maritime Ethnology Symposium at the Annual Meeting of the Canadian Ethnology Society (both in February 1977); observer–participant in Marginal Work World Project Workshop, Dalhousie University, Halifax (March 1977); a workshop in historiographic research in the Gulf of St. Lawrence, Maritimes, and Newfoundland, McGill University, Montreal (March 1977); the Labrador Resources Advisory Council Seminar, Ottawa (June 1977); and several others.

The Fishermen

In 1974 out of a total of 56 000 persons employed in the Atlantic Coast fisheries there were about 39 000 fishermen active on the major grounds (groundfish, lobster, herring). These fishermen are at the doorstep of one of the world's most productive fishing grounds and richest markets (the United States). But their labor adjustment does not fit conventional mainland industrial conceptions. In 1974 only about 5300 were classified as "full-time" (10 months or over) participants in fisheries. The others were classed as either "part-time" (5–10 months: 13 150) or "occasional" (less than 5 months: 20 500) fishermen. A breakdown of this employment by province follows (Anon. 1976b).

Extent of employment	Nfld.	N.B.	N.S.	P.E.I.	Que.
Full-time	903	445	3 912	30	31
Part-time	3 996	2 044	3 063	1 766	1 669
Occasional	10 414	2 409	3 485	814	4 003
Total	15 313	4 898	10 460	2 610	5 703

Unfavorable seasonal conditions and/or market limitations restrict the majority to part-time and occasional fisheries work. They find little alternative to being "occupational pluralists." For example, climatic conditions limit inshore fishermen to 5–5½ months of activity off southern Labrador, 8 months in the northeastern Gulf of St. Lawrence, and 9–11 months for various parts of the southwestern Gulf. Fishing is frequently combined with farming, logging, carpentry and construction work, subsistence production, and transfer payments to form a year's activity. Seasonal and pluralist work patterns have been followed by North Atlantic coastal peoples for centuries and they are generally acknowledged as an excellent "school" for self-reliance and individual resourcefulness and for recognition of opportunities and resources in an often harsh environmental setting. These work patterns therefore favor values of enterprise and individual resourcefulness. But the way these pluralist fishermen pursue their livelihoods in Atlantic Canada is little understood in a society oriented to industrial and occupational specialism.

Atlantic Fisheries Fleet

The Atlantic fisheries fleet is composed mostly of small fishing boats. More than 95% of the 28 910 boats are under 25 gross tons and generally operate within a day's run from home port. Many of these smaller boats are fishermen-owned and operated. There are also some 197 offshore fishing vessels of 100 feet length and over. These are owned by vertically integrated companies which catch, process, and market fish. These larger vessels work chiefly in the groundfish, herring, and scallop fisheries, and make up nearly one half the total investment in Atlantic Coast fleets. They also take about one half the regional fish catch.

This fisheries fleet is equipped to exploit a variety of species as demand and opportunity allow. The majority of inshore fishermen catch several species, e.g. groundfish, herring and lobster, in their year's effort. This requires a variety of gear and skills. The number and value of these vessels in the Atlantic provinces are given below (Anon. 1976b).

	Nfld.	N.B.	N.S.	P.E.I.	Que.	Total
No. of vessels	10 025	3 895	8 903	2 451	3 636	28 910
Value ($\times 10^3$ \$)	70 849	25 364	76 592	7 679	18 768	199 252

The Catch

In 1976 Atlantic Fishermen landed about 880 900 t (tonnes) of fish with an estimated landed value of $224.1 million and an estimated market value of $625.8 million. Catch and value on a provincial basis for 1976 are as follows (Anon. 1976b):

	Nominal catch (tonnes)	Landed value ($\times 10^3$ \$)	Market value ($\times 10^3$ \$)
N.B.	114 709	24 838	144 397
Nfld.	339 211	64 716	191 299
N.S.	367 883	106 686	251 705
P.E.I.	17 134	12 719	30 409
Que.	41 955	15 131	28 980
Total	880 892	224 090	625 812

Plant Employment

In 1973 the Atlantic catch was processed at about 405 fish plants of all sizes and kinds. These plants employed an average monthly total of about 16 600 persons in 1973 (10 800 male; 5800 female) in all shore capacities. These figures include average monthly totals of about 9700 male and 5300 female production workers, and 1100 male and 500 female sales and administrative personnel, many of whom are only seasonally employed (Anon. 1976a, p. 11). Secondary processing of fish landings in the Atlantic region generated a total plant work payroll of $77.6 million in 1973. Employment declined to about 14 236 in 1974. Plant employment figures for these two years by province are (Anon. 1976b):

	Nfld.	N.B.	N.S.	P.E.I.	Que.	Total
1973	5961	3340	5328	705	1296	16 630
1974	5171	2799	4451	540	1275	14 236

Vertical Integration

McCracken and Macdonald (1976, p. 8) argued that the number of fish plants (which they estimate at over 300) in the Atlantic Coast region belies the actual concentration of the fish processing industry. The offshore fleet, for example, was then owned by about 12

companies and took 70% of the Atlantic Coast groundfish catch. Since then, H. B. Nickerson and Sons Ltd., of North Sydney has declared its acquisition of over 50% of stock in National Sea Products Ltd. of Halifax. Is there a danger of monopoly fish buying and of further integration in this arrangement which affects the two largest fishing companies in Nova Scotia?

The data below give some idea of the scale of operations that might be created by integrating the business activities of these firms whose combined annual sales are estimated at $200 million (*Financial Post*).

National Sea Products Ltd.	H. B. Nickerson and Sons
Employees	
5000 directly	2000 in plants 500 in trawlers 4400 part-time and indirect employees
Fleet	
(In 1973) 18 stern trawlers ~150 ft long, 22 side trawlers (125–141 ft) 3 steel herring seiners 2 wood scallop draggers	40 vessels (includes 18 stern trawlers and 11 scallop draggers)
Plants	
7 major Canadian plants with annual capacities of up to 75 million lb, plus various smaller plants. Fishery operations at Rockland, Me., and Tampa, Fla.	3 major plants in N.S. 1 each in N.B. and P.E.I. 2 in Nfld.

One question is, To what extent is a vertically integrated company's commitment to competition in jeopardy through stock acquisition? We should also learn precisely where and how such an organization competes and what implications its operational scale and style has for our coastal communities and economies.

There is nothing naturally good or bad about large- or small-scale organizations. But increasing the size of an industrial operation generally results in a more formal management hierarchy and remote dominance. This diminishes the worker's sense of autonomy and "belonging." Growth is frequently accompanied by a management inclined to see its employees less as individuals and more as "biological machines" to be skillfully manipulated by incentives.

A recent assessment of the Canadian industrial scene reveals that the alienating effects of mechanization and automation, as in fish plant processing lines, have not been ameliorated despite the best efforts of unions and the growth of human relations programs in industry (Rinehart 1975, p. 121–123). How do we minimize worker alienation in our fleets and plants? This issue is specially pertinent to the larger vertically integrated companies.

Development Priorities for Atlantic Coast Fisheries

Successful development of the Atlantic fisheries within the 200-mile framework requires that we solve several problems. One is seen in a rather new context, i.e. equitable *access* to achieve the *maximum social benefit* for those who depend upon the fisheries. Other problems are quite familiar, e.g. the rationalization of capacity to the available resources, the improvement of harvesting, processing, and marketing and the need to stabilize earnings and profits against traditional uncertainties in supply and markets.

McCracken and Macdonald (1976, p. 29–30, 37) have suggested that fisheries development in Atlantic Canada requires a policy of "substantial and creative changes," if we are to escape from our long history of planning failures. The thrust of this recommendation is to restructure the decision-making process in fisheries so that the people dependent upon the fisheries will be able to meet and solve their own problems and thus be more productive. They recommend that "the ultimate aim should be citizen control and financial responsibility involving entrepreneurial and cooperative action in the private sector and strong democratically elected local and regional government."

This recommendation speaks directly to the political aspect of the (structural) changes postulated for the fisheries in Anon. (1976a). It is distinct from the more economic interpretation of structural changes as being largely centered upon balancing harvesting capacity with available resources and in consolidating and modernizing our presently fragmented and unprogressive marketing operations. In a news release dated February 8, 1977 the Fisheries Council of Canada took exception to the need for political structural changes advocated by the 1976 federal fisheries policy document. Their's is the economic view that "the underlying cause of the present state of industry is the depletion of the resource base and the resulting decline in catches and manufacturing throughput."

The need for social and economic impact assessment of these sorts of changes is clear; communities, occupations, entrepreneurship, regional, economic, and social adjustments are all involved. An obvious priority in view of the serious unemployment problem in eastern Canada is how to realize a maximum employment level. We will have to resolve the issue of how fisheries are to address our employment requirements. Are fisheries to be used as "reservoirs of opportunity" to absorb the unemployed or as the basis for a more limited employment of a highly specialized labor force? Income equity and life styles are clearly implicated here.

The shape of things to come in a changing political structure is less clear. This seems to involve new approaches and institutional frameworks for decision-making in fisheries so that individuals and communities may reduce their dependency on paternalistic industry and governments.

These issues of structural change are inseparably linked with every fisheries innovation. They figure prominently in relation to access and allocations, where the alternatives and their implications cannot be comprehended without the broadest possible inputs to the decision-making or planning process.

Atlantic Coast Fisheries — Who Shall Fish?

A fishery begins with *access* to the resource, whether exploitation is for subsistence or commerce. Where the resource is limited and fishing is susceptible to economic and social changes, a need develops to control access and harvest. Thus we have the beginnings of *fisheries management*. Biological conservation of stocks is not necessarily implied in fisheries management. When dealing with migratory species, such as cod, herring, and whales, management has for the greater part of history (and prehistory) been restricted to control over access to stocks found in coastal waters and rivers which may have been peripheral to the total range of these species with unknown biomass. In essence, access is confined to decisions about who has the right to fish in a given area over which a coastal or river people claim jurisdiction.[4]

Thus, decisions about access to fishery resources presume some *jurisdictional authority*. The power to make these decisions has been vested in coastal communities, fishing families, feudal lords or seigniors, companies, cooperatives, provinces, central governments, and international bodies such as ICNAF. In practise, access controls are asserted by a combination of *customary* and *enacted* legal restrictions. Fishermen and companies working within this framework also secretly use their individual and corporate tactics, skills, and resources to influence the distribution of access to aquatic resources between themselves and their competitors.

Access is thus a political matter and inseparable from socioeconomic determinants and consequences for fishermen and their livelihoods. These determinants and consequences include technological choices, capital management and marketing decisions, labor's commitment to the industry, and the contribution of the fisheries to the national interest. In Canada's case, we face the need for a steady-state fishery and for biological conservation of stocks but access has been a right vested in the existence of the coastal communities. Thus we must clarify what kinds of communities, if any, we wish to have along our coasts. That issue clarified, the problem of access management is somewhat simplified. We have not faced this issue head-on and, therefore, our fisheries management and development has been and remains less effective than it might be.

Access is the pivot to the future development of the Atlantic Coast fisheries.

Access Problem

Extended jurisdiction in 1977 carries with it the opportunity to manage and allocate fish stocks within this zone to the optimum social benefit of Canada, but as suggested above, this opportunity confronts fisheries management with the problems of inshore and nearshore versus offshore fisheries interests. On the face of it, the 12 vertically integrated fleets which dominate the offshore groundfishery represent a classic case of an effective technological system threatening a less effective one. Superior effectiveness means simply that an offshore vessel can range farther, fish more intensively, and operate in more extreme weather than can its "inshore or nearshore" counterpart.

There are countless historical cases of such technological conflicts which are usually resolved by setting some territorial limits to the operations of one or the other technology — hence, the idea of fishing boundaries and preserves or sanctuaries. Conflict is also controlled by gear restrictions, catch allocations and quotas, seasonal restrictions, and controls upon absolute numbers of units by type. Restriction on numbers of fishermen also has been used.

The choices from among alternative technologies neither affirm nor deny the total socioeconomic contribution a given technology makes to the fishery or the state. But they do assume a measurement of equity and a fair livelihood for the various participants. In the traditional sense, this assumption implies no more than a chance to fish without interference. In the future, this assumption may require assessment of the total socioeconomic contribution the different approaches make to the well-being of hundreds of large and small Atlantic Coast fishing communities. What does such an assessment require from the social sciences?

If we take as a first principle that effective access management in any fishery requires positive cooperation (not simply grudging conformity) from fishermen producers, buyer–processors, and government, two imperatives are established:

1. Formalized procedures that permit local participation in decisions about development and policies

[4]Access management in a variety of fisheries is discussed in several recent anthropological publications and papers in press: Acheson (1975, 1978) has described economic and ecological effects of territoriality in the Maine lobster fishery, which is usefully compared with East Coast Canadian lobster fishery management; Martin (1978) has examined access and space division in a Newfoundland inshore fishery; information management as a means of access control in the offshore or deep-sea trawler fishery of Newfoundland, and the North Atlantic more generally, is described in papers by Andersen (1972; 1973), and Andersen and Stiles (1973); Andersen (1978) has examined access management approaches from the inshore to offshore fishery sectors in the Newfoundland fisheries; Löfgren (1978) gives some insight into variations in coastal access systems in two Swedish contexts; and Smith (1974a, 1974b) examines the development of restrictions in the Oregon salmon fishery. These papers to some extent anticipate questions raised by fisheries under extended jurisdiction. But no social scientist to date has reported on access management under extended jurisdiction.

for fisheries and their management. In short, a radical departure from ad hoc consultative decision-making.

2. A continuing socioeconomic program to monitor the state of communities, industries, and occupations as they respond to the changing character of their marine biological resource base and to the larger system within which they operate.

Fisheries are *chronic* management problems. No matter what the regulative regime, whether for herring in the Bay of Fundy or redfish in the Gulf, there will always be a pushing and pulling against rules and boundaries. But these pressures reflect to some extent the changing character of the participants themselves as political and economic creatures. Hence, the need to monitor the "health" of fishery participants as well as the state of fish stocks.

There are some immediate problems that ought to be examined:

1. Canada's Atlantic Coast fisheries face an unusual opportunity presented by the removal of foreign fishing vessels from our waters. But what fishing fleet "mix" will be necessary to give us optimal social benefit? The amount of capital investment entailed in fleet expansion is great and an assessment of the relative *efficiency* of different mixes of fleets from technological, economic, and social standpoints becomes vital. There is mounting evidence that a high-technology offshore fleet may not be cost-effective in overall social terms despite its technological effectiveness in catching fish. For example, what will be the true socioeconomic cost to the Atlantic community if freezer trawlers are introduced to the offshore/nearshore fishing grounds? Should the offshore fleet be offset with increasingly efficient inshore/nearshore vessel adadjustments?[5] What about joint ventures?
2. More information is needed on alternatives in access management and their social and economic implications. For example, might we usefully assign sea tracts to local-level and regional interests for *their* management? There is a fundamental concern, expressed in the Fisheries Council of Canada news release (February 8, 1977) concerning the FMS 1976 policy document, that allocation of allowable catches among various sectors of the Atlantic fleet might become part of a long-term management policy. They reason this would perpetuate a status quo and this might impede logical fisheries development. This problem is apt to become acute in steady-state fisheries management. Fisheries management must be designed to enable progressive change and adjustment to take place.
3. Information is needed about the socioeconomic adjustment of fishermen in the high-value fisheries where entry is now restricted, viz salmon, shrimp, herring, lobster, scallops, and snow crab. Some cost and earnings information is being developed regionally on several of these fisheries but this work is quite recent and, as with a study of west coast Newfoundland shrimp fishermen, the results are based on a short time span. Of special importance is the relationship between fishermen in these high-value fisheries and other fishermen, especially those fishing for ground species. Attention must be directed to the social and economic framework for giving access to a few fishermen, so that they may be highly successful in economic terms.
4. How do innovations occur in our fisheries? There is need to examine the innovative process in social and cultural terms. Research should establish the "climate" that encourages (discourages) innovation among producers, buyer–processors and traders, and government itself. An examination of our "risk capital organizations" (DREE, Fisheries Loan Boards, Small Business Development Loan Funds) and how they work is needed. Is there greater wisdom in providing financial encouragement by indirect means (e.g. an improved tax structure) rather than through direct grants and subsidies? Examination of these questions requires attention to capital formation and management among small-scale or private fishermen. Individually and collectively, how do they cope with the increasing financial burden of new technology?
5. There is a widely shared belief that the Atlantic Coast fishermen need to be organized. The objective is greater control over factors affecting their well-being. But the form this organization should take is debated. Improvements in fishermen well-being and commitment have been achieved by both cooperative and union organizations. The gains of other kinds of "associations" seem less clear.

   Cooperatives are "economic structures owned and controlled by fishermen users. They imply investment, responsibility, involvement in all facets of business activities within their industry" (A. J. LeBlanc, President of the United Maritime Fishermen, Moncton, N.B., personal communication). Cooperatives in the Atlantic Coast fisheries date back at least to the 1920s. The United Maritimes Fishermen Ltd. of New Brunswick, for example, today has a membership of 3500 fishermen.

   Unions, by contrast, conventionally imply only the legal right to undertake collective bargaining. Union growth among fishermen has long been impeded by legal classification of fishermen as self-

[5]Note in this regard that the New Bedford offshore fleet is reportedly concentrated in the size range of 70–74 feet. Smith (1976: 4) reports that "vessels built in the past 10 years average 78 feet. Experienced fishermen in the port are quite consistent in preferring boats (stern trawlers) of approximately this size." Further, they see little difference between the efficiency of steel and wood hulls, although recently added trawlers tend to be steel.

employed and, where crews are involved, co-adventurers. This classification denied fishermen the right to organize for collective bargaining. It is increasingly regarded as an antiquated and destructive legality. In New Brunswick, although fishermen may organize in cooperatives under the law, they are still unable to organize as unions. This restriction is being challenged by many fishermen, as it was successfully done in Newfoundland prior to 1971.

Many fishermen are unorganized, especially those commonly known as part-timers and occasionals. The coastal fishermen of Labrador have fisheries committees on the community level which are represented on the recently (1976) organized Labrador Resources Advisory Committee. Many other fishermen are organized in relatively weak unions and associations. McCracken and Macdonald (1976, p. 7) estimate there are "40 exclusively fisheries organizations, often with little more than 20 members." By contrast, the Newfoundland Fishermen Food and Allied Workers Union (NFFAWU) claims a membership of about 6000. This includes nearly all Newfoundland's 1000 offshore fishermen and about 5000 inshore fishermen. The NFFAWU is widely acknowledged as a pacesetter among Atlantic Coast unions and seeks substantial structural changes along the organizational lines of the Norwegian fisheries. By contrast, the Nova Scotia Brotherhood of Railway, Transport and General Workers Union (Local 611) tends to follow conventional union paths; it stresses earnings, holiday time, fringe benefits, and work conditions.

The Atlantic Fishermen's Association, based in southwest Nova Scotia, is a recent (1976) entrant on the organizational scene. It tends to be a fishermen–entrepreneur's organization, embracing as it does boat owner-operators and fishermen. Its membership, perhaps 1000, are from one of the most successful of eastern Canada's inshore fisheries. Able to fish nearly the year-round in a diversified fishery, these fishermen are close to the United States fresh-fish market and command a high price for their catch in a highly competitive marketplace.

The Nova Scotia government recently decided to support by grant this association's organizational activities providing that they undertook to recruit inshore fishermen from all of Nova Scotia. The government's decision is interpreted by many as a choice among labor organization alternatives and thus reflects a biased, paternalistic approach to fishermen. The most significant alternative was the Guysborough County (Inshore) Fishermen's Association. This group has a reputation for militancy, particularly in promoting a 50-mile limit to protect inshore fishing, and southwest Nova Scotia fishermen sympathized with its efforts to bring greater protection of the inshore sector. A result of the provincial support is that the Atlantic Fishermen's Association is now viewed as a "sweetheart" association under government auspices and it may be some time, if ever, before it can organize the majority of Nova Scotia's inshore fishermen.

McCracken and Macdonald (1976, p. 7) summarized the situation: "The variety of organizations is indicative of a certain identification problem. Some fishermen see themselves as businessmen, others as labor to be organized into unions, and others as members of cooperatives." Thus, there are problems of different occupational adaptations and strategies which make commitment to associations of various kinds problematic. There is also much popular misinformation about cooperative management and purposes (see McCay, 1978) among fishermen in the Maritimes and Newfoundland.

6. There is need to examine prevailing concepts about the adjustments of full-time, part-time, and occasional fishermen within the framework of changing national and regional social orders. For example, offshore fishermen are generally regarded as full-timers and, hence, truly committed fishermen. But the Proskie and Adams (1971, p. 36) report indicated that in 1967, 23% of Newfoundland and 41% of Nova Scotian offshore fishermen spent less than 200 days at sea, and unions are now pressing for further reduction in sea time.

   Understanding of the actual intensity of labor investment in inshore and nearshore fishing activities is inadequate. It is often argued that a close look at inshore fishermen would reveal that they put in *more productive* hours during the 5½–6 months they fish than do industrial, mining, or service workers throughout a full year of regular employment. And their primary production is believed more valuable. Hours are measured here in *total* and include 6-day weeks plus "overtime" which frequently extends the day to 20 hours. There is need to remove the stigma applied to part-time fishermen for their "unemployed" blocks of time. How do we accomplish this?
7. *The 1976 Policy for Canada's Commercial Fisheries* does not specify how far the federal government is prepared to depart from its conservation-custodial role. While calling for structural changes in the industry, will the government also undertake structural changes in its relationship to industry, particularly concerning resource conservation and allocation? How much federal responsibility for fisheries development can be delegated or shared? This raises the need for a review of the various legislation under which federal fisheries management takes place.
8. Decentralization is particularly relevant in fisheries development. Special attention should be addressed

to the way FMS manages its authority and responsibility. The creation of new intermediate administrators (Area Managers) and subregions and of the Fishery Community Service Officers (FCSO) brings policy-interpretative/corrective functions almost to the grass-roots level. Both these developments are in an experimental stage. The wide-ranging responsibilities and functions of the FCSO, for example, may need revision and new emphasis to realize full potential. In theory the FCSO functions to facilitate a progressive outlook among fishermen and processors and some territorial dispute may surface between FCSO and provincial fishery extension and community development workers. Contradictory federal and provincial policies and different bureaucratic masters would also make conflict almost certain. It is true that the FCSO has permission to communicate "directly" to the federal Minister and this link may serve as a countervailing influence in case of excesses and inflexibility of the line organization.

There is danger that gains in grass-roots rapport will distract us from recognizing that these creations are not fundamental changes. They do not transfer responsibility to the fishery industry. Is this wise?

Precisely what structural changes should flow from administrative expansion to accommodate the new jurisdiction in fisheries? Working within the Fishery Act, what changes will promote responsible participation by fishermen and corporate interests to shape this industry? It is not sufficient to bring government "shopping lists" closer to the fishermen.

The recent transformation of the Bay of Fundy herring fishery to a high-value industry is a useful guide for structural change. FMS reportedly gave the purse-seine fishermen a quota and encouraged them to arrange allocation among themselves. They did so successfully, with gains in equity and earnings. The fishermen made the decision to sell their catch in the foreign food fish market. The federal government encouraged their organization, but the crucial decisions were left to them.

9. There is a complex and competitive interplay in fisheries and coastal resource development between federal–provincial, interprovincial, and interdepartmental groupings. The present "stalemate" relationship between Quebec and Ottawa is perhaps an extreme illustration of counterproductive interplay involving fisheries. The special managerial independence enjoyed by Quebec, dating back to 1922, has led to inconsistent regulations for licensing fishermen from Quebec and New Brunswick who operate in the same waters. Further, Quebec's insistence upon jurisdiction beyond the 3-mile limit conflicts with responsibilities of the federal government.

   As one government authority put it, "the present practice of each province developing its own master plan is bound to result in a lot of crap" as far as fishery rehabilitation is concerned. Each province will strive to gain as much control over the resource as possible.

   There is need to review these interrelations and policies and to identify "bridging mechanisms" to reduce and channel competition and conflict to more productive ends.

10. The efficiency of harvesting operations requires scrutiny. For example, firms operating offshore trawlers provide their skippers with codes for use in daily catch and location reports. These reports provide linkage between vessel supply and plant requirements and help to direct vessels to areas of high productivity. But trawler skippers "manage" the catch information they transmit to their plants to ensure primarily their *own* vessel's performance.

    This information management is tempered by periodic cooperation between small groups of skippers where long contact and friendship provide a basis for trust, but not every vessel in a given fleet is included in such cooperative networks. This competition among skippers stands in contrast to reported cooperative relationships among foreign fleets. Thus, problems exist in basic incentives and motivation among the fishermen in offshore harvesting. Research on harvesting becomes especially imperative in the present, demanding framework in which we have to fish.

    Information management as a means to establish and hold access privileges in offshore fishing is described by Andersen (1972, 1973) and Andersen and Stiles (1973).

11. There is a tendency to assume that scale of endeavor, quality-control, and efficiency are positively related. We must review our thinking that specific plant size ensures high levels of efficiency and quality control. Rationalization of the industry may require reduction in plant numbers but it may also require a more effective approach to establishing efficiency in all plant settings. Small-operator entrepreneurs may not be receiving the encouragement and information they need to achieve this. In larger plants, in urban locations, it is sometimes difficult to get employees to work nights or overtime, as compared to smaller plants in isolated locations where one has a "captive audience." The contradiction between workers seeking a guaranteed 40-hour work week while refusing to work overtime when fish need to be processed must be resolved. "Seasonal plants" are seen as essential to tap resources, and workers in seasonal plants are more willing to work long hours, but these plants need fish to extend their work season.

    In addition to the need for improved processing facilities and more efficient use of existing plants, changes in worker–management relations must be considered. Management can no longer rely on its

power to acquire labor commitment. As one plant manager put it, "The days of going down the line with a "bull whip" are over. There must be a total change of attitude on the part of management, unions, and workers. We should expect to get a fair day's work for a fair day's pay." Fish-plant worker–management relations and community life in Atlantic Canada need to be examined by social scientists. This need includes fish-plant work routines and conditions. It is significant that the only comprehensive study of single-industry towns in Canada (Lucas 1971) does not even mention fish-plant towns, although it does recognize mining and lumber towns. Plant operators have generally recruited private consultants to study their operations but documents resulting from these studies seldom reach the scientific community. They do not contribute to a broader enhancement of knowledge relevant to regional and local social and economic issues.

12. The explosion in fisheries technology since the Second World War has given us a great variety of vessels and gear. For example, our offshore fleet is highly varied, including side and stern trawlers, ground and/or midwater fishing gear, slow and high-speed diesel power (with different noise-level implications), and varied deck arrangements and dimensions. This technology sets varied crew requirements and work organization practices aboard ship, such as watch assignments, allocation of specialized tasks, especially winch operation, numbers of men involved on deck and in the engine room at various times, etc. Work safety and training are also involved. Has this complexity been fully grasped by the various government departments responsible for the safety and health of fishermen? Is there need to examine the safety and health policies and practices of fishery companies?

    Attention should be focused upon the application of regulations affecting the well-being of fishermen, their vessels, and the fishing operations. For example, if we want information today about health problems in alternative fishing technologies (e.g. small vs. large trawlers) we are forced to extrapolate from findings based upon American and European research. This assessment is based upon scrutiny of medical-health titles and selected articles pertinent to fishermen and seafarer occupations published in the period 1966–77. Such extrapolation suggests danger in too casual an approach to implications for the health of fishermen associated with different technologies and work regimes. Our ability to generate new fishing technologies exceeds our capacity to anticipate their potentially detrimental human implications. Offshore fishing, despite improved technology, remains characterized by physical hardship, high rates of injury, and great mortality risks.

    A preliminary review of information specific to health in eastern Canadian fisheries communities suggests that little has been done. Health concepts and practices in a northern Nova Scotia fishing–farming village have been examined by Davidson and Davidson (1969) and Davidson (1970), but these do not relate health to livelihood in fisheries. Lip cancer among Newfoundland fishermen was examined by Chambers and Spitzer (1977) and Spitzer et al. (1975), and one still confidential federal study completed in 1971 examined income security provisions available to survivors of fishermen who die at sea.

    The recent *Proposal for Analysis of Safety and Health Needs in Deep Sea Fishing Industry* by the Newfoundland Fisherman, Food and Allied Worker's Union recommends a pilot study to identify the scope of the problem in Newfoundland. It might be broadened to a study of the Atlantic region fishermen's work conditions, health and security. Actual treatment of fishermen compensation claims should be scrutinized in such an overview (Leyton 1976). This study should clarify how health and welfare influence recruitment, commitment, effort, and efficiency in primary and secondary fisheries production. It also should establish the relation between quality of life, health, and security as functions of livelihood in the fisheries industry.

13. There is a need for systematic acquisition of information on fisheries management and development outside Canada. Such comparative information is needed on our principle competitors for resources and markets. The series of *Fisheries Reports* on various producing nations provided by Industry, Trade and Commerce (ITC), is valuable, but largely statistical. We need organizational and structural information.

14. There is frequent mention of "fishing communities in Atlantic Canada" but this term is a rather unserviceable abstraction. These coastal communities vary so much in socioeconomic character as to preclude application of "blanket" development and assistance programs. We do not understand the interdependencies between fishermen, their enterprises, and their households with other communities and groupings that enable them to adjust to commercial activities. The introduction of new technologies, services, and subsidy programs and the new fisheries management regime require us to examine the fishing communities in Atlantic Canada and to make certain that they have a viable future.

    There is particular danger that we may retain a static, "traditional" notion of the "fishing community" in our decision-making and ignore the transformational implications of technological developments for inshore fisheries. An understanding of these communities in transition is also essential in arriving at effective access management systems.

Copes' writings (1972), for example, may tend to unnecessarily polarize our appreciation of the Atlantic fishing communities.

We must recognize that many people prefer the life-style or quality of life in smaller fishing settlements over other alternatives. As Mathews (1976, p. 138) has argued, "many people do not define quality of life purely in materialistic terms. Many are willing to give up some of the modern amenities if they can live in their local communities."

Community restructuring (or "rationalization") under fisheries rehabilitation is more than a "cost-benefit" exercise and an economic efficiency matter. Decision-making must take account of non-materialistic values and must involve the people most directly affected.

Conclusion

I have distinguished between additive and qualitative change in the structural transformation of Atlantic fisheries. Additions call for "more of the same," with temporary improvement possible for some, until our growth prospects meet the limits of renewed stocks available to us under preferential fishing within the 200-mile management zone.

A fishery restructured by "addition" is synonymous with "rationalization," such as the desire to bring landing places to more efficient numbers and arrangements, to ensure processing units and capacity are more in tune with production, in market consolidation, etc. "Additions" imply continuation of a paternalistic approach to fisheries and may not foster the "self-determined" fishery of which federal policy speaks.

Qualitative change, however, suggests a different and more progressive style. The option of qualitative structural change requires a different and broader understanding. Structural change of the fisheries industry would be oriented to decision-making arrangements that bridge the boundaries of a traditional industrial order. And, at least in theory, it would realize better a fisheries adjustment soundly balanced against a limited renewable resource base and would provide an equitable and socially desirable work and community life-style for those who depend on fish.

The fisheries equation includes human and bio-environmental factors of constantly changing magnitudes. Management and development are therefore *chronic* problems. The human and nonhuman sides of this equation require *systematic monitoring*. The argument that our "fishermen have been studied to death" (Byrne 1974) may be fashionable, but it is false. Much of our knowledge of the human factors — fishermen adjustment, their communities, industry, and government — in the fisheries management and development process is fragmentary and, because of extended jurisdiction, obsolescent.

In this void, decision-making about stock allocations and fisheries industry development, and their impacts on people, are, at best, crude approximations of what is wise. Filling this void requires a program of systematic research focused upon the human component in our fisheries.

II. Priorities for Investigation

The following are specific social science investigations that need to be done as a basis for policy development:

1. Decision-making alternatives for fisheries management — especially from the standpoint of socio-economic and administrative sciences. Information on certain foreign nations' approaches to modern fisheries will be available soon from the Fisheries Rehabilitation program, but detailed monitoring of these fisheries as ongoing organizations will be required.
2. The legal and administrative constraints upon FMS to devolve parts of its management responsibility through deliberative structures, such as a Gulf of St. Lawrence Fishery Advisory Council. The examination should determine what beneficial results might ensue.
3. The socioeconomic impact of current access restrictions in high-value fisheries (lobster, herring, scallop, tuna, etc.) and the ground fisheries. Alternative proposals should indicate probable costs and degrees of desirability.
4. Current federal and provincial fisheries approaches to the "development process" with particular attention paid to vessel and gear financing and incentive programs, new technology for quality control, and innovation in vessel design. The examination should propose alternative structures to ensure coordination of federal and provincial initiatives.
5. The impact of marketing consolidation upon small buyer–processor–traders. This analysis should include the social and economic role they play in each province and important fishery.
6. The constraints and incentives that affect fisherman organizations. This must be multiprovincial and embrace the unions and other associations and the consequences of their development to the Atlantic fisheries. The cooperative movement should be dealt with as financial enterprises subject to a special regulatory regime.
7. The various categories of fishermen and processing-workers, viz full-timers, part-timers, and occasionals, to understand their adaptations and place in the fisheries environment.
8. The occupational work-organization of foreign offshore fleets. This should be done by qualified individuals and not necessarily by observers on various vessels for fisheries protection and conservation purposes.
9. An examination of socioeconomic factors is needed to ascertain a socially "optimal-fleet mix."

This would require consideration of the "relative efficiencies of small, intermediate, and large fishing boats with their various technologies." The future role of foreign trawlers in joint ventures would be considered for their contribution to fisheries communities.

10. Selected fishing communities and regions to ascertain how their distinctive characteristics, such as geography, socioeconomic history, and social composition, might have contributed to their prosperity. Comparisons of communities and regions would provide information on different development needs.
11. Health and safety practices in the fisheries industry.
12. The role of the Fisheries Community Service Officers "at the front." Attention should be directed to their contribution to fisheries and fishing community development.
13. The occupational "cultures" of (a) inshore–nearshore and offshore fishermen, and (b) fish-plant workers and managers. These should be oriented to efficiency and worker welfare in harvesting and processing, but should also include training and recruitment incentives, union influence in the work place, and worker activity.

III. Current Human Science Research Effort in Atlantic Fisheries

An attempt to establish current expenditures for human sciences research in the Atlantic regional fisheries community has proven difficult. Major government departments, including Statistics Canada and the Ministry of State for Science and Technology, do not gather or isolate their data in such specific terms. Even Canada Council, the major national funding agency for research in the social sciences and humanities, was unable to provide this information, short of a manual search through its files. Similar problems are found at individual universities where the development of a systematic assessment of research funding and effort is in its infancy. Precise knowledge of Canada Council funding exists for two long-term research efforts, the Marginal Work World project at Dalhousie University and the Maritime History Group project at the Memorial University of Newfoundland — but both of these are peripheral to contemporary fisheries.

Information available on Canada Council and National Research Council expenditures (MOSST 1977) indicates *all* programs in human sciences across the nation will be supported by $32 million in 1977–78. Support for natural sciences research in 1977–78 by contrast, includes direct expenditures of at least $271 million. Expenditures by other federal departments and agencies will increase support for science and technology research in 1977–78 by a further $229 million. The portion of this support to go to human research is unknown. Additional support also is available from provincial governments. How much is uncertain.

The Honourable Hugh Faulkner, Minister of State for Science and Technology, recently indicated that research bearing upon our renewable resources, such as fisheries, will receive stronger support. There is no indication that this concern will lead to increased programs to improve information about the human side of our fisheries. The Department of Fisheries and the Environment will have to assume leadership in developing such research. At this writing, DFE subventions and NRC grants favor the aquatic sciences (oceanography, aquatic environmental quality, resource management, etc.).

In DFE, Fisheries and Marine Service social science (economics, sociology, and statistics) personnel as of November 1975 (Caissie and Willmer 1976, p. 28–29) numbered 55 out of a total of 807 scientific and professional personnel (an approximate ratio of 1 social scientist to every 16 natural scientists). Fifteen of these social scientists were in the Atlantic region (10 in Maritimes, 5 in Newfoundland) and 29 in Ottawa. (Decentralization and staff growth in the regions may have changed these figures somewhat.)

But DFE has *no programs* supporting extramural human sciences research in fisheries. DFE has supported university and other contract research into human problems only on a sporadic basis in response to crises. The Fisheries Management Project conducted by the Institute of Oceanography at Dalhousie (Dalhousie University 1977) is illustrative.

The resources given to directed research in human sciences in support of fisheries in the United States are quite substantial. This directed support has given a major push to information dissemination at the local and regional level. Strong extension publication and public service programs oriented to coastal people and management concerns have been developed around Sea Grant programs centered at coastal institutions (e.g. Oregon State University). These information programs are closely linked with progress in both basic and applied research on a broad multidisciplinary front. In 1977 the combination of Sea Grant funding programs and extended jurisdiction has triggered a sharp increase in social science research activity oriented to fisheries management concerns.

In Atlantic Canada, government and some universities operate needed extension-information services, but the linkage between them and research on fisheries is weak. Institutional mechanisms are needed to bring extension service and human research in fisheries closer together. DFE information programs, in the absence of human sciences research programs for fisheries, do not fill this gap. Their *content* strength lies on the biological side of fisheries management.

Centers of Expertise and Capability in Human Sciences

Human sciences research capability and expertise

directly pertinent to fisheries and coastal community problems is primarily located among a fragmented body of specialists in Atlantic region universities and colleges. Research information is exchanged informally and irregularly. Having very limited funds for travel, these specialists rarely meet to exchange information. Institutional telephone budgets are also highly limited and impose a restriction even on telephone communication.

There are three centers of human science expertise and special capability for mobilizing long-term investigation into fisheries and coastal socioeconomic adjustment: Laval University at Quebec City, the Memorial University of Newfoundland at St. John's, and Dalhousie University at Halifax.

Laval University

This university has a full-time staff of about 20 anthropologists, about 5 of which have considerable experience with fishing and other coastal populations of the Quebec Gulf coast, especially the Lower North Shore, Gaspé, and Magdalens. The major social science knowledge about the society and economy of Quebec coastal people has come from researchers like Yvan Breton, Paul Charest, Claude Bariteau, and André LePage.

Laval University social scientists have traditionally investigated basic and applied problems. Their work has involved several long-term projects on Gulf of St. Lawrence regional economy, the forest industry, family economics, psychiatric services, studies of native peoples (social change, community life), and historical–cultural and ecological studies of Lower North Shore peoples. The last program mentioned was under Canada Council support over several years. Much of the resultant information is still being analyzed and written up.

The applied or practical orientation of these researchers as it relates to fisheries problems is illustrated by Paul Charest's (1978) study of developing political organization on the North Shore, and most recently, by Yvan Breton's proposal for an investigation of the impact of transfer payments (hence, social legislation) on fishermen enterprise along the Lower North Shore. This project was part of a 5-year Program Grant submission, *PROPONORD*, to Canada Council in 1976. The larger proposal was not funded. (Graduate programs have been heavily involved in these projects.)

The list of published and unpublished documents resulting from the Laval research is too extensive to give here. Charest's (1973) discussion of cultural ecology on the Lower North Shore of the Gulf of St. Lawrence is a useful introduction to their scope. Likewise, no attempt is made to list the extensive publications resulting from work at other institutions discussed in this document.

Other Laval University scholars doubtless have interests in Quebec coastal people, and fisheries, but they are scattered among history, economics, sociology, and other departments. It also seems that the primary interests of these other departments are in macrosocietal and economic problems.

Research funding has become extremely tight at Laval, as elsewhere, in recent years. There is little work on contemporary fisheries problems underway. More significant, the investigators with greatest expertise in fisheries are in the process of shifting their efforts to other areas, such as urban affairs, where support exists for significant research.

Memorial University of Newfoundland (MUN)

Beginning in the early 1960s, the Institute of Social and Economic Research (ISER) undertook to encourage study of various pressing social and economic issues as Newfoundland was undergoing rapid modernization. ISER Fellowship and research programs led to what is perhaps the most distinctive and concentrated body of information on modern fishing people to be found in our literature. ISER also has a strong publishing program (see *ISER Reports* for 1965–71 and 1971–74 available from the Institute's Publications Secretary). Social anthropologists have led in these efforts. Their community and *comparative* fisheries studies are now basic reading among students of modern fisheries. ISER studies and papers describe Newfoundland fishing communities and occupations from the inshore to the offshore fishery. And they include some comparative information on other North Atlantic fishing states (e.g. Norway and Sweden); the development of comparative fisheries information has been stressed for at least a decade and ISER has sponsored research in the Maritime Provinces of Canada, and in Iceland, Norway, Faroes, Shetland, and Portugal, much of which is still being written up. Some of this work has resulted in M.A. and Ph.D. theses. Completed work, however, ranges over the following topics: fishermen cognition and symbolism, management of marine space and fish resources, crew recruitment and organization, class structure and modernization, fisheries and community development, and fisheries policy.

A number of MUN geographers, historians, and economists, and staff in the Center for Community Initiatives, also actively pursue research on various fisheries problems. Although there are no multidisciplinary or interdisciplinary fisheries projects underway among these MUN scholars at present, there is a general awareness of their importance. This is perhaps evidenced by the *Report of the Committee on Federal Licensing Policy and Its Implications for the Newfoundland Fisheries* (MUN 1974). This report resulted from the cooperative effort of scholars from several disciplines. It is also indicated by the development of *Marine Man*, an *interdisciplinary* newsletter for students of man in maritime settings, published by MUN anthropologists from 1970 to 1974. Publication ceased for lack of funds.

ISER has no special program or block of funds

specifically assigned to human studies in fisheries and other coastal problems. Fisheries studies are one among several ISER priorities. Research effort is determined annually by competitive assessment of submissions from six member disciplines (anthropology, economics, geography, sociology, political science, and linguistics); ISER support extends outside these disciplines in individual cases. Some of these departments are moderately large (Anthropology has 14 people, Geography, 19) and ISER funds (exclusive of administrative allocations) lately annually amount to only about $50 000. Awards support M.A. and predoctoral fellowships ($2400 and $5000, respectively), an occasional postdoctoral fellowship, and research by permanent faculty. Competition is therefore intensive and individual awards relatively small. Supplemental funds are also obtained from other university and external sources. But the research environment is highly constrained. With the possible exception of one or two economists, it seems that no MUN social scientist receives support for work in fisheries management, etc. from DFE, or from provincial fisheries.

The present core of strength at MUN for future fisheries research from a human standpoint consists of about seven anthropologists (George Park, Tom Nemec, Geoffrey Stiles, Rex Clark, Louis Chiaramonte, Gordon Inglis, and Raoul Andersen), two economists (Steven Antler and S. S. Mensinkai), one economic historian (David Alexander), a geographer (Stan Nowak), and several sociologists (F. A. Johnstone, L. Felt, and R. Schwartz).

ISER, however, magnifies this capability substantially in the ability to mobilize and administer projects involving large numbers of researchers recruited from far afield for long- and short-term projects. Many of the researchers mentioned maintain strong communication ties with maritime human sciences researchers elsewhere around the North Atlantic.

In 1977 MUN social anthropologists, in cooperation with individuals from Dalhousie University, had planned to launch a 5-year investigation (*Coastal Hinterlands of the Industrial State*) focused upon North Atlantic rural coastal populations. This project was to take a "microregion" approach and depart from the conventional community-study method in anthropology. It would thereby deal more effectively with the multisectoral (e.g. fisheries, forestry, mining, welfare) and multicommunity character of contemporary coastal social and economic life. Many of the problems, e.g. migration, local-level planning and control, fishermen labor and economic change, etc., to be examined have direct importance to fisheries management. Canada Council did not fund this study, however, and the associated researchers are now redesigning their future plans.

MUN is to establish a special program for fisheries and marine affairs. This program may be expected to encourage basic and applied human sciences training and research on fisheries.

Dalhousie University

To date, only a few Dalhousie University studies bearing on fisheries have been produced in the human sciences. Noteworthy is a faculty dissertation (Steinberg 1973) on collective bargaining in the Nova Scotia fishery, and several M.A. theses. A few other studies are in progress. Unlike Laval and Memorial, Dalhousie has only one anthropologist (Leonard Kasdan) with a well-defined commitment to research relevant to fisheries management.

A number of Dalhousie and other university social scientists in the area are in the 2nd year of a 5-year study, *Public policy formation and the marginal work world in the Atlantic provinces*. This project, shaped in part by arguments advanced by Brox (1972) in his study of Newfoundland fishermen, is relevant to fisheries planning in its attention to the political culture of marginal workers. Only one of the studies, a survey examination of UIC, *Special Fishermen's Benefits and Its Effects*, however, deals specifically with a fisheries problem.

The recently completed *Fisheries Management Project* (Dalhousie University 1977) conducted by the Institute of Oceanography (I.O.) focused upon biomathematical fisheries management questions. Somewhat tangentially, it also addressed some "people questions" in pilot inquiries into "occupational pluralism" and Newfoundland and Nova Scotian trawler fishermen attitudes to their occupation. No fully trained social scientists were involved in these inquiries. Despite its interdisciplinary billing, I.O. had concentrated upon natural science problems. This situation may change as there is an awareness of the distinctly social and economic character of long-term fisheries management research problems. Two I.O. staff members are attempting to organize a genuinely interdisciplinary graduate-level course on renewable resource management.

A primary capability at Dalhousie in the study of human problems associated with fisheries is found in its Institute of Public Affairs (IPA). Over its 35-year history, IPA has worked in four interrelated areas:

1. Industry, with programs in management development, labor education, and labor management relations;
2. Public administration, with emphasis on local government;
3. Regional and urban studies, with focus on economic, social, and governmental issues;
4. Services to citizens, organizations, and community groups.

Like ISER at Memorial, IPA has an established publication program. Their most direct contribution to fisheries management problems is Johnston et al. (1975).

Each of the universities discussed above has staff experience and institutional wherewithal capable of undertaking long-term human science investigations for

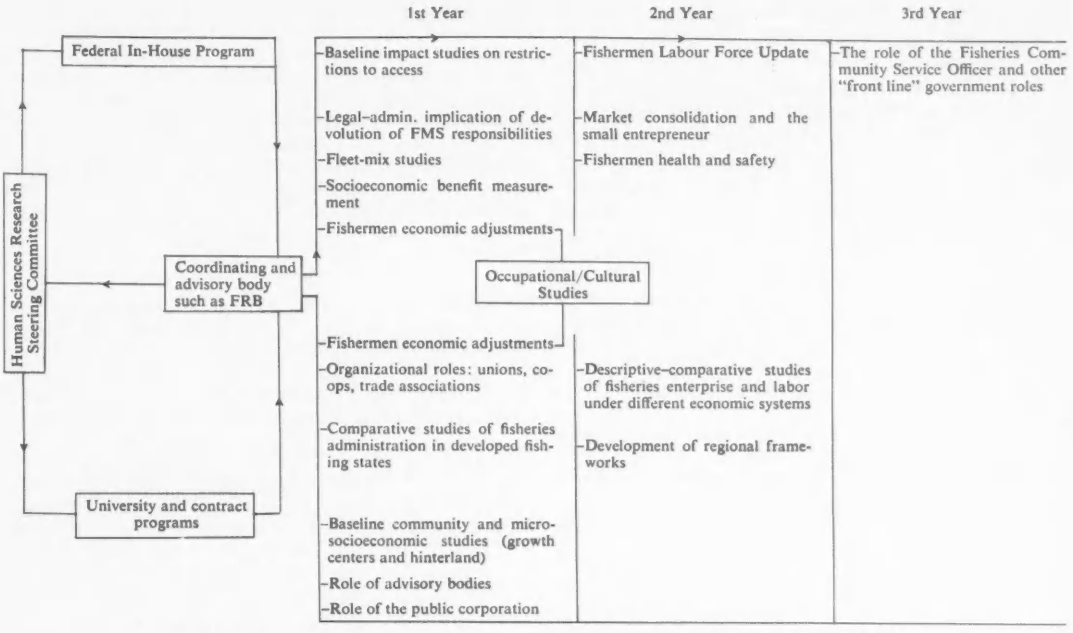
1st Year
2nd Year
3rd Year
Federal In-House Program
Human Sciences Research Steering Committee
Coordinating and advisory body such as FRB
University and contract programs
Baseline impact studies on restrictions to access
Legal–admin. implication of devolution of FMS responsibilities
Fleet-mix studies
Socioeconomic benefit measurement
Fishermen economic adjustments
Fishermen Labour Force Update
Market consolidation and the small entrepreneur
Fishermen health and safety
The role of the Fisheries Community Service Officer and other "front line" government roles
Occupational/Cultural Studies
Fishermen economic adjustments
Organizational roles: unions, co-ops, trade associations
Comparative studies of fisheries administration in developed fishing states
Descriptive–comparative studies of fisheries enterprise and labor under different economic systems
Development of regional frameworks
Baseline community and micro-socioeconomic studies (growth centers and hinterland)
Role of advisory bodies
Role of the public corporation

FIG. 1. An outline of a human sciences research program for the Atlantic Coast Fisheries (as derived from Parts I and II of the study).

fisheries. Only Laval and Memorial, however, have concentrated efforts in fishermen and fisheries studies as such. Their social anthropologists, in particular, following their customary methods, have emphasized work at the "ground level," i.e. detailed accounts of fishermen and their views in the context of changing coastal communities and occupations. This orientation may be distinguished from the more "macrolevel," or survey methods, used in many sociological, economic, and public administration approaches to understanding regional, social, and economic problems. Both approaches make contributions.

These comments have stressed "centers of expertise" or institutions now most active in *basic* research related to fisheries management problems. There are also a number of individual social scientists with various fisheries research involvements scattered among other institutions in the Atlantic provinces.

Among these "other" institutions, it is important to note that St. Francis Xavier social scientists and its Coady Institute staff have, since 1928, pioneered work related to the socioeconomic development of fishing and other rural communities. They have been strong in encouragement of fishermen to organize cooperatives and are still active in community development work.

This overview of current human sciences research for fisheries management in Atlantic Canada leads to several conclusions.

1. No systematic program of research focused upon fisheries, the fishing community, and fisheries management is now underway in our universities. (By contrast, a long-term multiuniversity program has just been funded by the U.S. government for a social anthropological study of extended jurisdiction and fisheries management impact upon fisheries communities from Rhode Island to Maine. Projects are being organized for other management areas.)
2. In the absence of an incentive for this research, existing human science experts may soon drift into other problem fields with an irretrievable loss in depth of expertise.
3. Existing knowledge of coastal communities, fishermen, and fisheries problems rapidly becomes outdated. The most substantial period of nongovernmental human science research into fisheries was in the mid- to late 1960s. Activity has gradually dropped off among Atlantic area researchers as university research and administrative budgets precipitously declined. Little new research is now underway, and there is a net loss in manpower and research.
4. A decline in recent years in employment opportunities for human scientists in our teaching institutions, due largely to declining enrollment, means no significant growth in our university research manpower will occur in the near future.

Hence, what manpower fisheries lose now to other problem areas may not be retrievable.

5. University researchers with established and pertinent fisheries management interests are primarily locked into teaching positions and, in view of lack of funds to "buy" their way free of teaching responsibilities, are largely unable to launch significant new research in fisheries management. This is true precisely when human problems in fisheries management in Atlantic Canada are vastly different in scale and form. DFE presently has no program to alter this situation.

These findings lead me to advance the following recommendations.

PRIORITIES FOR MOBILIZING HUMAN SCIENCES IN ATLANTIC COAST FISHERIES

1. The federal government make a commitment to provide a human sciences research program for fisheries development on the Atlantic Coast.
2. A Human Science Research Steering Committee be constituted to recommend a specific human sciences research program be undertaken as part of the overall scientific research for the Atlantic Coast fisheries.
3. An agency such as the Fisheries Research Board be given the mandate to direct and coordinate the research program and to advise the federal government on human sciences in relation to policy for the fishing industry on the Atlantic Coast.

A program of research directed and shaped by the proposed steering committee should be expected to address immediate and long-term fisheries management problems. The committee would work closely with the federal government and other fisheries interests to overcome immediate shortcomings in baseline community social and economic information and management impact assessment. A framework for effort is suggested in Fig. 1.

Responsibility for liaison with university (and other) external researchers, and for insuring a continuing program of support for human science research in fisheries, might wisely be assigned to the Fisheries Research Board. This could facilitate improved ties between industry, government, and university social scientists. Some changes in its design might be required, but this redirection of its historic science responsibilities would be consistent with the new appreciation of the importance of human issues in fisheries management.

Acknowledgments

The FRB Human Sciences committee was chaired by D. Kendall, and included M. Brechin, I. Langlands, J. A. LeBlanc, and P. Russell, with W. MacKenzie and Dr A. W. H. Needler, Acting Chairman of the Fisheries Research Board of Canada, as ex officio members. I am indebted to all of them for their patient advice and critical suggestions, and hope this document indicates some of what they have taught me. Dr W. R. Martin, FRB Senior Scientific Advisor, and others proved invaluable sources of advice, for which I am most grateful. I owe a great sum of gratitude to E. B. Stolee, FRB Secretary, for flawlessly guiding a "cadet" and this report to its conclusion. I am certain it seemed at times like trying to move the carrier *Bonaventure* up the Rideau Canal. I am also indebted to Chris Isaacs, who masterfully translated my numerous drafts in hieroglyphics and artfully composed and typed this report. Its shortcomings are my responsibility.

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BOOK REVIEWS/COMPTES RENDUS

Book review editor:
David P. Scott
Department of Fisheries and the Environment
Fisheries and Marine Service
Freshwater Institute
501 University Crescent
Winnipeg, Man. R3T 2N6

Thermal Ecology II. *Proc. of Thermal Ecology Symp., Augusta, Georgia, April 2–5, 1975. Edited by Gerald W. Esch and Robert W. McFarlane. National Technical Information Service, U.S. Dep. of Commerce, Springfield, 1976. ix + 404 p. $13.50.*

The 57 articles comprising this book were selected from 105 papers presented at the 1975 symposium Thermal Ecology II sponsored by the U.S. Energy Research and Development Administration and the University of Georgia. I recommend it to biologists and others who are interested in recent research on effects upon marine, estuarine, and freshwater organisms of low-grade heat discharge into the aquatic environment. Users will find the report loosely divided into six main sections: Temperature and Physiological Parameters; Thermal Tolerance, Temperature, and Fish Behavior; Populations, Communities, and Ecosystems; Environmental Impact; and Impingement and Entrainment Effects.

The invited presentation by J. W. Gibbons on "Thermal Alteration and the Enhancement of Species Populations" emphasized the utilization of heated effluent as an energy source to develop positive returns in aquatic populations. Genetic selection is noted as a necessary step towards beneficial uses of waste heat.

A second invited speaker, J. Cairns Jr., makes a justifiable plea for standardization of procedures for assessing thermal effects on aquatic systems.

Among the reports on temperature and physiological parameters, the presentation by C. I. Gibson et al. demonstrates the importance of evaluating the effects on aquatic invertebrates of the interaction of waste heat with such common components of power plant effluents as chlorine and copper.

Papers by D. K. Cox, C. C. Coutant, and W. R. Wolters deal with the effects of "cold shock" on fish. Of particular interest was the vulnerability of cold-shocked young bluegill fish to predation by unstressed adult largemouth bass. A cold shock of 9°C was sufficient to cause increased vulnerability to predation.

In a study of entrainment of herring, shad, and striped bass eggs, J. R. Schubel and T. S. Y. Koo argue for the highest ΔT that can be safely used with a corresponding decrease in the volume of cooling water discharged to the aquatic system. They recommend a ΔT of 10 to 12°C during spawning of anadromous and semianadromous species in Chesapeake Bay. At the present time Maryland restricts temperature differentials to 5.6°C in its region of the Chesapeake Bay.

A paper on host–parasite population dynamics by J. M. Aho et al noted that brain parasites in mosquitofish were more numerous in fish from heated waters than from thermally unaltered areas. In contrast, the density of body cavity parasites declined in fish from areas with high water temperature.

An interesting paper by R. C. Baird and J. A. Watson on the location of power plants considers the advantages of siting power stations in the vicinity of the freshwater–saline interface on large river systems. They propose that the environmental impact from thermal discharges would be minimal in this marginal habitat dominated mainly by hardy marine and estuarine forms. Potential damage, through impingement of anadromous or resident fish populations might be reduced through proper location of the intake pipes.

In another estuarine study, T. T. Polgar et al showed radical depletions in zooplankton populations near a power plant that could not be accounted for by cooling systems or delayed entrainment mortalities. They attributed these "near-field" changes to avoidance reactions and to mortalities (of an undisclosed nature) in the vicinity of the plant.

While the majority of the papers tend to repeat subject matter covered in the initial 1974 conference on thermal ecology (Gibbons and Sharitz 1974), there appears to be an increased interest in thermal effects in relation to the marine–estuarine environment. This information is timely in view of the current attention to coastal sitings of proposed power stations. The limitations of available fresh waters in the United States for "once-through" cooling and legislative restrictions on temperature increases above the ambient are forcing electrical utilities to reassess current siting policies.

The volume of reading material might have been significantly reduced through more severe editing of introductions, study area descriptions, and superfluous materials and methods sections which in some instances tend to be repetitive.

The book binding is unfortunately substandard. The two copies I used literally fell apart, page by page, on the first perusal.

J. W. McMahon

Biology and Health Physics Division
Atomic Energy of Canada Limited
Chalk River Nuclear Laboratories
Chalk River, Ont. K0J 1J0

(R150)

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February 1978

Shrimp and Prawn Farming in the Western Hemisphere. *Edited by Joe E. Hanson and Harold L. Goodwin. Dowden, Hutchinson and Ross, Inc., Stroudsburg, Pa., 1977. xiii + 439 p. $30.00.* (Subtitled "State-of-the-Art Reviews and Status Assessments," the book is a compilation of presentations and discussions on shrimp and prawn culture made at two workshops, one at Galveston, Texas, and the other at Charleston, South Carolina.)

The Environment of Amchitka Island, Alaska. *Edited by Melvin L. Merritt and R. Glen Fuller. Technical Information Center, Energy Research and Development Administration. Available as TID-26712 from National Technical Information Service, U.S. Department of Commerce, Springfield, Va. 22161, 1977. xii + 682 p. $20.00.* (Development of the Spartan antiballistic missile warhead, tested underground on Amchitka Island, led to a massive study of pre- and postexplosion ecology of the island. This volume is the publication of that work.)

Marine Recreational Fisheries 2. *Edited by Henry Clepper. Sport Fishing Institute, Washington, D.C., 1977. vi + 220 p. $15.00.* (Proceedings of the 2nd annual symposium on marine recreational fisheries, held in San Francisco, California, April 6–7, 1977.)

Hunters, Seamen, and Entrepreneurs: The Tuna Seinermen of San Diego. *Michael K. Orbach. University of California Press, Berkeley, Calif., 1977. x + 304 p. $12.75.* (An intimate socioeconomic study of the tuna seinermen community of San Diego, California; the book is written in story style, rather than the usual dry-as-dust scientific tome.)

100 Years of Oceanography. Essays commemorating the visit of H.M.S. Challenger to Halifax, May 9–19, 1873. *Edited by Eric L. Mills. Dalhousie University in cooperation with Nova Scotia Museum, Halifax, N.S., 1975. ii + 89 p.*

COMING NEXT MONTH/À PARAÎTRE LE MOIS PROCHAIN

Incidence, microscopy, and etiology of exoskeleton lesions in the tanner crab, *Chionoecetes tanneri*
J. A. Baross, P. A. Tester, and R. Y. Morita

Stress response of coho salmon (*Oncorhynchus kisutch*) elicited by cadmium and copper and potential use of cortisol as an indicator of stress **C. B. Schreck and H. W. Lorz**

Evaluation of an aerial survey of Pacific walruses (*Odobenus rosmarus divergens*)
J. A. Estes and J. R. Gilbert

Circulation in an open bay **B. Petrie and K. Drinkwater**

Rates of mortality, growth, and biomass production of *Lymnaea palustris* during chronic exposure to lead **U. Borgmann, O. Kramar, and C. Loveridge**

Nitrogen transformations within the trophogenic zone of lakes **C. F.-H. Liao and D. R. S. Lean**

Permanent sedimentation of N, P, and organic C in a high arctic lake **L. de March**

Effects of the polychlorinated biphenyl Aroclor® 1254 on growth, survival, and bone development in brook trout (*Salvelinus fontinalis*) **W. L. Mauch, P. M. Mehrle, and F. L. Mayer**

Histopathological and physiological responses of *Fundulus heteroclitus* to naphthalene exposure
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Seasonal changes in nitrogen compartments of lakes under different loading conditions
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Notes

A device to simulate the variability in sunlight intensity for laboratory cultures of algae
C. M. Boyd and J. Marra

Distribution of humpback whales (*Megaptera novaeangliae*) in the Caribbean determined by a rapid acoustic method **C. Levenson and W. T. Leapley**

Acoustic detection of demersal fish closer than 15 centimetres to the bottom in 80 metres of water
M. H. Orr, E. E. Hays, and F. R. Hess

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Les nombres qui suivent les titres de chacune des séries désignent les établissements suivants à la fin de la section.

Recent Studies

Until 1970, reprints of these articles had been included in an annual volume of "Studies," composed of two parts. The final binding was the 1969 Studies, Part 2, which included No. 1355. These are no longer bound and distributed. We continue, however, to number and list all articles on investigations published in other periodicals, which henceforth may be obtained in reprint form only from the author or originating establishment.

Récentes études

Jusqu'en 1970, ces articles étaient réimprimés, puis reliés dans un volume annuel d'études, comprenant deux parties. Les études de 1969, partie 2, incluant le n°1355, ont été les dernières à être reliées. Nous n'en faisons désormais plus la reliure ni la distribution. Nous continuons cependant de numéroter les articles et d'en établir des listes d'études sur des recherches mentionnées dans d'autres périodiques. On peut donc se les procurer, sous leur forme réimprimée seulement, de l'auteur ou du service dépositaire.

2487. ACKMAN, R. G., AND C. A. EATON. 1977. Specific gravity of rapeseed and canbra oils. J. Oil Chem. Soc. 54: p. 435. (8)

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2489. MANSFIELD, A. W. 1973. The Atlantic walrus *Odobenus rosmarus* in Canada and Greenland, p. 69–79. *In* Proc. of a Working Meeting of Seal Specialists on Threatened and Depleted Seals of the World, held under the auspices of the Survival Service Commission of IUCN, Guelph, Ont., August 1972. (5)

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2491. MITCHELL, E. D., AND D. G. CHAPMAN. 1977. Preliminary assessment of stocks of northwest Atlantic sei whales *Balaenoptera borealis*. Rep. Int. Whaling Comm. Spec. Issue 1: 117–120. (5)

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This new series commenced in 1966. The articles interpret work already published in primary journals. They appear at irregular intervals in various technical publications. Frequently an article essentially duplicates, condenses, or is based on an article in another series.

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398. PAYNE, J. F. 1978. Petroleum, a pollutant in search of toxicity? Mar. Pollut. Bull. 9: 54–55. (9)

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This series includes unpublished preliminary reports and data records not intended for general distribution. They should not be referred to in publications without clearance from the issuing establishment and without clear indication of their manuscript status.

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1436. LEE, J. C., AND N. BOURNE. 1977. Marine resource inventory of Pacific Rim national park — 1976. 375 p. (1)

1437. HAEGELE, C. W., AND R. D. HUMPHREYS. 1977. Assessment of herring spawnings in the vicinity of Nanoose Bay, B.C. 37 p. (1)

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1439. CADDY, J. F. 1977. Some approaches to elucidation of the dynamics of sword fish (*Xiphias gladius*) populations. 10 p. (6)

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The following translations have been prepared by or for the Fisheries and Marine Service, for use in its investigations. Copies are available from Translation Services, Canada Institute for Scientific and Technical Information, National Research Council of Canada, Ottawa, Ontario K1A 0S2, at a cost of 22¢ per page and a minimum charge of $2.20. Information on translations can be obtained from the Scientific Information and Publications Branch.

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ANNOUNCEMENTS / AVIS

Water Research Committee Seeks Canadian Members

The Canadian National Committee (CNC) of the International Association on Water Pollution Research (IAWPR) is inviting applications for membership from qualified Canadian societies, institutes, associations, and industries. Organizations concerned with environmental research may become members of the Canadian National Committee, which, through its representation on the IAWPR Governing Board, is active in various international activities and assignments. Although organizations make up the membership of the CNC, individuals are encouraged to become members of the parent body (IAWPR); they will receive the monthly journal *Water Research* which publishes results of original research in the field of water quality management and water pollution control. *Progress in Water Technology*, published by IAWPR every 2 months, contains the proceedings of IAWPR conferences.

Historically, Canadians have been prominent in IAWPR affairs and the CNC promotes the exchange of research information by providing a Canadian regional Editor for the IAWPR journals.

The CNC also encourages and supports Canadian participation in IAWPR regional, specialized, and biennial conferences by assisting Canadian authors and reviewers to take part. The 1980 IAWPR Conference will be held in Toronto and is expected to attract some 2500 scientists from all over the world.

In the years ahead, the CNC/IAWPR will strive to improve its services to the Canadian scientific community, and to advance the objectives of water pollution research and information exchange on the international scene. Therefore, the CNC is now seeking to broaden its membership.

Details can be obtained from the CNC Secretary, Dr W. A. Bridgeo, c/o Bridco Values Limited, P.O. Box 3161, South Post Office, Halifax, N.S. B3J 3H5.

Le Comité de recherche sur les eaux veut recruter des Canadiens

Le Comité national canadien (CNC) de l'International Association on Water Pollution Research (IAWPR) invite sociétés, instituts, associations et industries canadiens qualifiés à poser leur candidature comme membres. Les organismes qui s'occupent de recherche sur l'environnement peuvent devenir membre du Comité national canadien. Comme il est représenté sur le Bureau de direction de l'IAWPR, le comité est engagé dans diverses activités et missions internationales. Le CNC ne comprend que des organismes. Cependant, les individus peuvent devenir membres de l'Association-mère (IAWPR); ils recevront le périodique mensuel *Water Research*, où sont consignés les résultats de recherches originales dans le domaine de la gestion de la qualité des eaux et du contrôle de la pollution des eaux. *Progress in Water Technology*, publication paraissant tous les 2 mois de l'IAWPR renferme les comptes rendus des conférences de l'IAWPR.

Les Canadiens ont, dans le passé, joué un rôle de premier plan dans les affaires de l'IAWPR. Le CNC lui-même favorise les échanges d'information scientifiques en fournissant un rédacteur régional canadien pour les périodiques de l'IAWPR.

Le CNC encourage également la participation canadienne aux conférences régionales, spécialisées et biennales en accordant une aide permettant aux auteurs canadiens d'y prendre part. La conférence de 1980 de l'IAWPR aura lieu à Toronto et on s'attend que quelque 2 500 scientifiques du monde entier s'y rendront.

CNC/IAWPR s'efforceront, dans les années à venir, d'améliorer leurs services à la communauté scientifique canadienne et de faire progresser la recherche sur la pollution des eaux et les échanges de connaissances sur la scène internationale. C'est pourquoi le CNC cherche maintenant à élargir ses cadres.

Pour plus de détails, veuillez vous adresser au secrétaire du CNC, M. W. A. Bridgeo, a/s Bridco Values Limited, Case postale 3161, Bureau de poste sud, Halifax, N.-E. B3J 3H5.

Sailing Directions and Small Craft Guides/Instructions nautiques et Guides du plaisancier

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17. *Small Craft Guide, British Columbia*, Vol. I, 3rd ed., 1976, 200 p.
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19. *Small Craft Guide, Trent-Severn Waterway*, 2nd ed., 1975, 46 p.
20. *Guide du plaisancier, Voie d'eau Trent-Severn*, 2e éd., 1975, 48 p.

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OCEAN DUMPING REPORT 1

(La version française est en préparation)

Methods for Sampling and Analysis of Marine Sediments and Dredged Materials

A. WALTON (ED.)

This report documents methods for sampling and analysis of marine sediments and dredged material. It is intended that the report serve as a reference and guide to those engaged in field and laboratory investigations carried out for the purposes of the Ocean Dumping Control Act and Regulations. Reviews are presented of sampling, storage, and preservation methods for marine sediments. Physical methods of classification of sediment types and textures are described in addition to geochemical analytical methods. Additional chemical tests are included where these are relevant to circumstances described in the statute.

Ce rapport explique les méthodes d'échantillonnage et d'analyse des sédiments marins et des matières draguées. Il est destiné à servir de guide et de référence à ceux qui participent à des travaux sur le terrain ou en laboratoire prescrits par la Loi sur l'immersion de déchets en mer et le règlement qui en découle. Il présente des résultats d'études sur les méthodes d'échantillonnage, d'emmagasinage et de conservation des sédiments marins et en décrit les modes de classement par types et par textures, ainsi que les techniques d'analyse géochimique. Les épreuves supplémentaires nécessaires en raison de circonstances prévues par les instruments législatifs pertinents y sont aussi décrites.

(1978, 74 p., Cat. no. En 35-601/1; Free/Gratis)

Available from:
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Department of Fisheries and the Environment
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240 Sparks St. — 7th Floor, West
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RECREATIONAL FISHERIES BRANCH PUBLICATION

Sportfishing in Newfoundland — a Survey of Anglers

KENNETH W. COX

During the fall of 1974 various federal and provincial government departments involved in the sport fisheries of Newfoundland undertook a study to generate a data base as well as to develop a continuing data system involving the socioeconomic characteristics of Newfoundland anglers. Data for this study on sportfishing were derived from a mail-out survey of 7500 people, stratified into resident and nonresident groups. The edited data were coded, keypunched, and verified before processing, using the Statistical Package for the Social Sciences (in particular two subprograms, Fastabs and Condescriptive). The report includes a description of the resource (its organization and licensing), a profile of anglers (their activities, preferences, effort, and catch), and expenditures and investments related to the Newfoundland sport fishery. Freshwater and saltwater fisheries have been used to differentiate between the orientation of angling in the Province. A total of 99 000 resident and 8500 nonresident anglers fished 2.3 million days during 1974. On the average, resident anglers fished 22 days and nonresident anglers 6 days. These anglers spent about $12.8 million; residents spent about $10.9 million or $253 per family, and nonresidents spent $1.8 million or $322 per family. As well as presenting a data base for the sport fishery in the Province, the report should provide a better understanding of the role and dimensions of angling in the Province. This will be of interest to the general public as well as to the various sport fisheries managers.

(1977, 61 p., Cat. no. Fs 99-11/1977; Free)

Available from:
Department of Fisheries and the Environment
Fisheries and Marine Service
Recreational Fisheries Branch
240 Sparks Street
Ottawa, Canada K1A 0E6

PUBLICATION DE LA DIRECTION DE LA PÊCHE SPORTIVE

La pêche sportive à Terre-Neuve — enquête sur les pêcheurs sportifs

KENNETH W. COX

Pendant l'automne 1974, les divers ministères fédéraux et provinciaux qui s'occupent de la pêche sportive à Terre-Neuve ont entrepris une étude afin de recueillir des données sur les caractéristiques socio-économiques des pêcheurs sportifs à Terre-Neuve. Les données de la présente enquête sur la pêche sportive ont été obtenues à partir d'un questionnaire adressé par la poste à 7 500 personnes réparties en groupes de résidents et de non-résidents. Une fois révisées, les données ont été codifiées et vérifiées avant le traitement, en utilisant l'ouvrage *Statistical Package for the Social Sciences* (surtout deux sous-programmes, soit *Fastabs* et *Condescriptive*). Le rapport comprend une description de la pêche sportive (son organisation et la délivrance de permis), un profil des pêcheurs sportifs (leurs activités, leurs préférences, leurs efforts et leurs prises), ainsi que les dépenses et les investissements se rattachant aux activités de la pêche sportive à Terre-Neuve. Pour plus de précision, nous avons divisé la pêche sportive en deux catégories: la pêche en eau douce et la pêche en eau salée. Au cours de l'année 1974, 99 000 pêcheurs sportifs résidents et 8 500 non-résidents ont pratiqué la pêche pendant 2,3 millions de jours. En moyenne, les pêcheurs sportifs résidents ont pratiqué ce sport pendant 22 jours et les non-résidents, pendant 6 jours. Ces pêcheurs sportifs ont dépensé environ 12,8 millions de dollars; les résidents, environ 10.9 millions ou $253 par famille, et les non-résidents, 1,8 million ou $322 par famille. Tout en fournissant une banque de données sur la pêche sportive dans la province, le présent rapport devrait permettre de mieux comprendre le rôle et l'ampleur de ce sport à Terre-Neuve, ce qui intéressera sans doute tout autant le grand public que les divers gestionnaires des pêches sportives.

(1978, 67 p., Nº de catalogue Fs 99-11/1978F; Gratis)

Disponible à:
Ministère des Pêches et de l'Environnement
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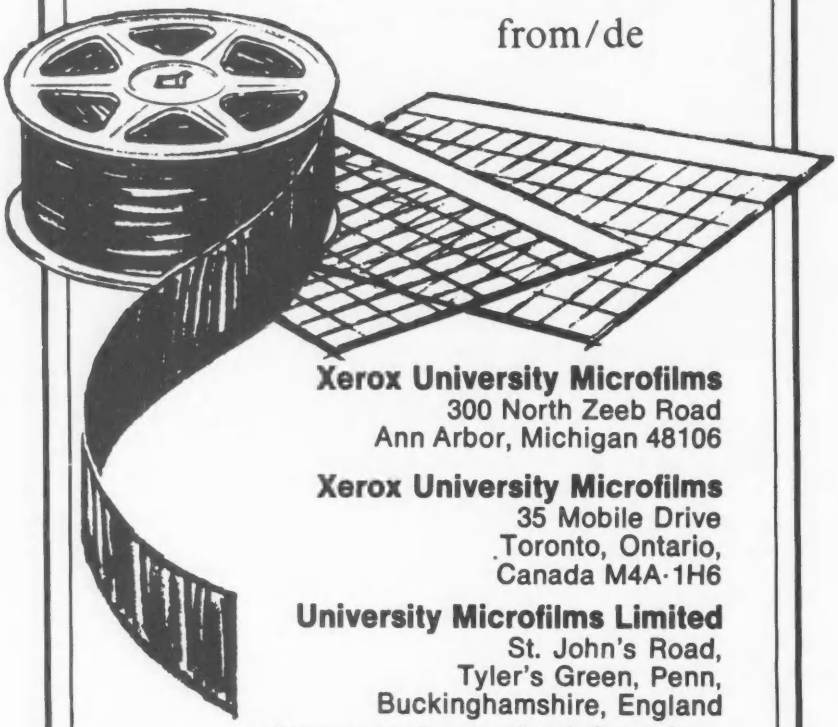

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Unités et symboles SI

Nous encourageons l'usage des unités SI (Système international d'unités) et des symboles pour le *Journal de l'office des recherches sur les pêcheries du Canada* pour la liste des quantités ci-dessous. Le *Guide canadien de familiarisation au système métrique* (CAN3-Z234.1-76), que l'on peut se procurer auprès de l'Association canadienne de normalisation, 178, boul. Rexdale, Rexdale (Ontario) M9W 1R3, donne une liste plus complète des unités.

Quantity/Quantité	Name/Nom	Symbol/Symbole
length/longueur	centimetre, kilometre .../centimètre, kilomètre ...	cm, km ...
area/aire	square centimetre .../centimètre carré ...	cm^2 ...
volume/volume	millilitre, litre .../millilitre, litre ...	mL, L ...
time/temps	second/seconde	s
	minute/minute	min
	hour/heure	h
	day/jour	d
frequency/fréquence	hertz/hertz	Hz
mass/masse	gram, kilogram .../gramme, kilogramme ...	g, kg ...
density/masse volumique	kilogram per cubic metre/kilogramme par mètre cube	kg/m^3
pressure/pression	pascal/pascal	Pa
temperature/température	degree Celsius/degré Celsius	°C
electric current/courant électrique	ampere/ampère	A
conductance/conductance	siemen/siemen	S
luminous intensity/intensité lumineuse	candela/candela	cd
illuminance/éclairement	lux/lux	lx
amount of substance/quantité de matière	mole/mole	mol
molar concentration — volume/ molalité concentration — volume	mole per cubic metre/mole par mètre cube	mol/m^3
molar concentration — mass/ molalité concentration — massique	mole per kilogram/mole par kilogramme	mol/kg
ppm (parts per million)	microgram per gram/microgramme par gramme	$\mu g/g$
	milligram per litre/milligramme par litre	mg/L
	millilitre per litre/millilitre par litre	mL/L
ppb (parts per billion)	nanogram per gram/nanogramme par gramme	ng/g
	microgram per litre/microgramme par litre	$\mu g/L$

The following units are not acceptable in the SI and authors using them are asked to give SI equivalents. If both units are given it is preferable to put the non-SI one in parentheses.

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Not acceptable in SI/ Non valides dans le SI	SI equivalents/Équivalents SI	Conversion factors/ Facteurs de conversion
ångström/ångström (Å)	nanometre/nanomètre (nm)	1 Å = 0.1 nm
micron/micron (μ)	micrometre/micromètre (μm)	1 μ = 1 μm
calorie/calorie (cal)	joule/joule (J)	1 cal = 4.1868 J
inch (in)/pouce (po)	centimetre/centimètre (cm)	1 in/1 po = 2.54 cm
foot (ft)/pied (pi)	metre/mètre (m)	1 ft/1 pi = 0.305 m
mile/mille (mi)	kilometre/kilomètre (km)	1 mi = 1.6 km
curie/curie (Ci)	becquerel/becquerel (Bq)	1 Ci = 37 GBq

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Volume 35, No. 7, July 1978

Volume 35, nº 7, juillet 1978

Fecundity changes in exploited populations of lake whitefish (*Coregonus clupeaformis*) and lake trout (*Salvelinus namaycush*) **M. C. Healey** 945–950

Acceptability of rapeseed proteins in diets of rainbow trout (*Salmo gairdneri*) **M. Yurkowski, J. K. Bailey, R. E. Evans, J.-A. L. Tabachek, G. B. Ayles, and J G. Eales** 951–962

Elevated heavy metals: a stress on a population of white suckers, *Catostomus commersoni*, in Hamell Lake, Saskatchewan **G. A. McFarlane and W. G. Franzin** 963–970

Diel food selection by two sizes of rainbow trout (*Salmo gairdneri*) in an experimental stream **P. A. Bisson** 971–975

Chemical and sensory analysis of ungutted offshore (nonspawning) capelin (*Mallotus villosus*) stored in ice **J. R. Botta, P. B. Noonan, and J. T. Lauder** 976–980

Larvae and pelagic juveniles of blackgill rockfish, *Sebastes melanostomus*, taken in mid-water trawls off southern California and Baja California **H. G. Moser and E. H. Ahlstrom** 981–996

Effects of Aroclor® 1248 and 1260 on the fathead minnow (*Pimephales promelas*) **D. L. DeFoe, G. D. Veith, and R. W. Carlson** 997–1002

Notes

Ammonia quotient in sockeye salmon (*Oncorhynchus nerka*) **M. N. Kutty** 1003–1005

Distance chemoreception and vision in the selection of prey by American lobster (*Homarus americanus*) **R. W. M. Hirtle and K. H. Mann** 1006–1008

Fish cell lines: comparisons of CHSE-214, FHM, and RTG-2 in assaying IHN and IPN viruses **R. K. Kelly, B. W. Souter, and H. R. Miller** 1009–1011

Ionization of ammonia in seawater: effects of temperature, pH, and salinity **C. E. Bower and J. P. Bidwell** 1012–1016

Perspectives

Management alternatives and strategic planning for Canada's fisheries **W. F. Sinclair** 1017–1030

The need for human sciences research in Atlantic Coast fisheries **R. Andersen** 1031–1049

Book Reviews/Comptes rendus: Thermal Ecology II. Proc. of Thermal Ecology Symp., Augusta, Georgia, April 2–5, 1975 (G. W. Esch and R. W. McFarlane [ed.]) **J. W. Gibbons and R. R. Sharitz** 1050

Books received/Livres reçus 1051

Coming next month/À paraître le mois prochain 1052

Recent publications/Récentes publications 1053–1056

Announcements/Avis 1057

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